Perceptual or Motor Decoupling? An investigation into the genesis of errors in the Sustained Attention to Response Task

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“It’s not worth doing something unless someone, somewhere, would much rather you weren’t doing it.” – Terry Pratchett

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Chapter 1

1.1 The Absent Mind

Adam Smith was a Scottish economist from the 18th century who is often called the father of modern economics. He was also a philosopher, an author, and was considered to be amongst the greatest minds of his generation. Once, while entertaining a visitor at breakfast, it is said that he was gesticulating with a piece of toast and was so caught up in his diatribe that he placed this piece of toast into his tea pot. Done with the discussion he swirled the tea around in the pot and poured himself a cup. Upon sipping the tea his face twisted with disgust and he proclaimed that this was unequivocally the “worst cup of tea he ever met with” (McLean, 2006). In a similar vein, there are stories of Sir Isaac Newton boiling his watch instead of the egg he was meant to be cooking. But they are not the only ones, have you gone looking for your glasses while they lay safely on your forehead? Have you tried to brush your teeth with facewash instead of toothpaste? Or maybe you have shown up to work on a holiday? If so, you can consider yourself to be in some esteemed company. Despite being incredibly intelligent, these men and you will still make mistakes or slips that every other human being has and will make several times during the course of their lives.

Some would consider these episodes to be a simple case of absent mindedness or an action slip, defined as being inattentive to ongoing activity, losing track of current aims and becoming distracted from the intended thought/action by (currently) irrelevant stimuli (Manly, Robertson, Galloway, & Hawkins, 1999; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Others may say that it is because you have failed to remain vigilant, referring to the ability to maintain attention and to remain alert to stimuli over prolonged periods of time (Davies & Parasuraman, 1982; Warm, Parasuraman, & Matthews, 2008). Norman Mackworth (1948) famously began the systematic study of vigilance during World War II.

He ran experiments that attempted to determine why airborne radar and sonar operators on antisubmarine patrol failed to report weak signals on their displays that signified the presence of enemy submarines, in particular toward the end of a watch.

Since then there have been many vigilance or sustained attention tasks that required participants to monitor visual displays or auditory streams for rare target stimuli over long periods of time (Helton, 2009). Despite the now amusing examples from earlier, the ability to sustain attention is often vital to successfully complete daily activities. A lapse of attention can sometimes have costly consequences, an airport security officer missing a concealed weapon, a soldier accidentally firing on a comrade, or inappropriately reacting to traffic signals. Given the importance of attention in everyday life, a lot of research has been dedicated to the study of sustained attention or vigilance. An issue that clinicians and neuropsychologists have faced has been the inconvenience of the long duration of traditional vigilance tasks often making the task overly arduous for their subject (Helton, 2009). But it was discovered that the task duration may not be as important as many researchers were led to believe (Posner, 1978), and so shorter tasks that shared features with their longer counterparts were created. The most popular tasks today are the Continuous Performance Task (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) where subjects detect a single letter (X) or a letter sequence (X followed by A); the Abbreviated Vigilance Task (AVT; Temple et al., 2000) which is a 12 minute signal detection task; and most relevant to this thesis: the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

1.2 The Sustained Attention to Response Task (SART)

In 1996, Robertson and his colleagues were investigating how brain damage (mostly frontal lobe) increases the likelihood that an individual would be more prone to action slips. They argued that action slips in the normal population share characteristics with the attention failures of traumatically brain injured patients (in a less extreme way). Robertson and colleagues believed that attentional performance measures that correlated with slips of action (in the normal population) had not been very successful due to what they considered inadequate or contaminated measures of sustained attention. They suggested that there was insufficient characterization of attention deficits in patients with Traumatic Brain Injury (TBI) and the existing (at the time) difficulty in establishing dependable performance correlates of sustained attention failures in TBI patients may be due to the nature of the sustained attention paradigms employed. Thus, motivated by the apparent lack of a suitably brief and valid test of attention failure they developed the SART.

Robertson and colleagues believed that by reversing the relative probability of and go stimuli (or targets and non-targets) they could create a situation where responses to the common stimuli become automatized. So instead of looking for the rare stimulus to respond to, subjects would need to look for the rare case where they should not produce a response. They argued that without sustained attention to their responses participants would mindlessly execute the automatized pre-potent response ongo trials. Thus, the frequency of responses to go or withhold stimuli (i.e. commission errors) provides the sought (sensitive) measure of a person’s ability to sustain attention. To test their hypotheses Robertson and colleagues conducted a set of studies involving both patient groups and normal control subjects. These studies explored the relationship between SART measures and everyday attention lapses, other cognitive failures and the severity of brain damage.

The SART itself is a very simple procedure. It involves the visual presentation of a semi random sequence of the digits 1 to 9 repeated 25 times (total 225 trials), which is completed in just over 4.3 minutes. Each digit is displayed for 250 ms followed by a mask (an encircled X) for 900 ms (see Figure 1.1).

Subjects are instructed to respond to each digit (except 3) with a key press (go stimuli), and to make no overt response on the 25 (11.1%) occasions that the digit 3 (nogo stimulus) was presented. The digits were randomly allocated to five different font sizes in an attempt to ensure that numerical value rather than unique visual feature was used to distinguish the go digit from the set of digits.

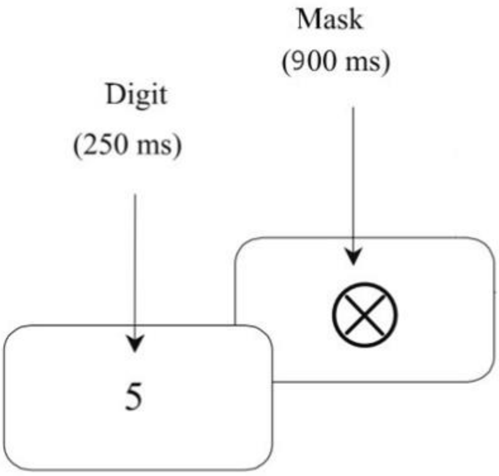


Figure 1.1 A single trial sequence during the SART

Robertson and colleagues found that the number of commission errors (overt response to the go digit 3) committed by normal control subjects, correlated with their self-reported rates of attention lapse and ‘cognitive failures’ in everyday life and with reports by informants of their everyday rates of similar failures. The SART measures demonstrated strong relationships with validated measures of sustained attention (Robertson et al., 1997) but weaker relationships with other measures of attentional capacity that were considered by

Robertson et al. to involve response inhibition and other components. Additionally, Robertson and colleagues were able to predict errors of commission (key presses to withhold stimuli) based on performance on correct trials preceding the presentation of a target, i.e. subjects' response times (RT) speed up prior to commission error responses. This was consistent with their argument that an error is not just an isolated failure in withholding a response but the result of a failure to maintain an optimum approach for the duration of the task.

Since many psychiatric disorders involve controlling urges (in a way similar to performance on the SART), there is research that has looked at the cognitive neuroscience of "stopping". There are two paradigms of stopping - reactive and proactive stopping (Aron, 2011). Reactive stopping is when subjects stop a response when instructed to do so by a signal whereas proactive stopping is developed based on the goals of the subject rather than an external signal. Many studies (Aron, Robbins, & Poldrack, 2004; Molenberghs et al., 2009) indicate two broad regions of the prefrontal cortex that are vital for stopping: the right inferior frontal cortex (rIFC) and the dorsomedial frontal cortex (in particular the presupplementary motor area, preSMA). The two regions are said to work in harmony to deliver a STOP command to intercept the process through the basal ganglia. Aron (2011) suggests that whereas reactive stopping involves completely revoking the initiated response, proactive stopping involves a preparatory step before the response is triggered and this can occur on a trial-by-trail basis. Aron (2011) also suggests a third stopping mechanism he calls "hold-your-horses" where a subject presses a "brake" on response tendencies when conflict is found. Interestingly, O'Connell et al. (2008) used event related potentials (ERPs) to show that errors in a go/nogo task similar to the SART can be caused by either sustained attention failures or by failures in response inhibition and that the two processes are dissociable.

A study by Aharoni et al. (2013) using functional magnetic resonance imaging (fMRI) demonstrated changes in the brain’s hemodynamic response in the Anterior Cingulate Cortex (ACC), an area which is associated with the ability to supress unwanted behaviour (Aharoni et al., 2014). They used a SART-like task to locate neurocognitive biomarkers that might assist in predicting rates of future re-arrest of offenders. They found that the odds of a re-arrest were approximately double when the subject had lower anterior cingulate cortex (ACC) activity than normal during the task. Another study by Steele et al.(2014) reported a fMRI study involving a SART-like go/nogo task which aimed to delineate neural systems involved in errors. Several regions were identified during error processing including the ACC and the sub thalamic nucleus. They argue that brain areas that are responsible for error processing often overlap with those observed in successful response inhibition. The rostral portion of the ACC has been associated with error appraisal and the dorsal portion with response conflict and error monitoring.

In the three decades following the introduction of the SART, researchers have used it to explore attention functions in a wide variety of populations and contexts. In addition to seeing use as an agent to investigate the effect TBI on sustained attention (R. C. K. Chan, 2005; Dockree et al., 2006; Whyte, Grieb-Neff, Gantz, & Polansky, 2006), the SART has been used to study ADHD (McAvinue et al., 2015; R. G. O’Connell, Bellgrove, Dockree, & Robertson, 2006), sustained attention in schizophrenia (Hoonakker, Doignon-Camus, Marques-Carneiro, & Bonnefond, 2017; Seok et al., 2012), the efficacy of narcolepsy treatments (Van Der Heide et al., 2015) and to further investigate sleep disorders (Guaita et al., 2015; Van Schie et al., 2012). It has been used to investigate attention in down syndrome (Faught, Conners, & Himmelberger, 2016), Huntington’s disease (Hart et al., 2015), early Alzheimer’s disease (Huntley, Hampshire, Bor, Owen, & Howard, 2017), and in migraines (Kam, Mickleborough, Eades, & Handy, 2015). It has seen use as an instrument to measure the effect of stress on attention (Alomari, Fernandez, Banks, Acosta, & Tartar, 2015; Linden, Keijsers, Eling, & Schaijk, 2005), the effect of music (Baldwin & Lewis, 2017), glucose (Birnie, Smallwood, Reay, & Riby, 2015), anxiety (Grillon, Robinson, Mathur, & Ernst, 2016) and age on attention (Carriere, Cheyne, Solman, & Smilek, 2010). It has even been used to study the implications of natural disasters like earthquakes on cognition (Helton & Head, 2012; Helton, Head, & Kemp, 2011), and friendly fire situations (Wilson, Head, & Helton, 2013; Wilson, Head, de Joux, Finkbeiner, & Helton, 2015). Researchers have even used the SART to investigate the effects of chewing gum (Johnson, Muneem, & Miles, 2013) and chewing betel nut (Ho, Li, & Tang, 2015) on attention, and to look the possible effects of meditation on attention (Cardeña, Sjöstedt, & Marcusson-Clavertz, 2015; MacLean et al., 2010). Given its wide application any demonstration that the SART may not provide a valid measure of sustained attention throws into doubt the widespread conclusion that people having scores deviant from normal necessarily suffer problems sustaining attention.

1.3 The Debate

Chan, (2001) called the SART a “theoretically sound measure of sustained attention”. Indeed, the assumption thus far has been that the SART measures or assesses attention lapses. In particular, the SART’s rapid pace and frequency of responding results in an automated response, and that in order to effectively counter the strong tendency to respond subjects must actively monitor their actions (Seli, 2016). Based on this assumption, when participants experience a lapse of attention, the automatic response is initiated and failure to successfully execute a withhold action results in a commission error on go trials. It is expected that a proportion of responses to stimuli will also be made automatically. In a follow up study to the original, Manly, Robertson, Galloway, & Hawkins, (1999) reiterated their argument that performance on the SART requires sustained attention rather than a putative response inhibition capacity (Verbruggen & Logan, 2008, 2009). They argued that performance is determined by the duration over which a person must maintain attention over their actions and that this demand supports the SART's relationship to common attention lapses.

We know that human beings mind-wander intensely (Axelrod, Rees, Lavidor, & Bar, 2015) and perhaps that mind-wandering occurs during as much as half our waking hours (Killingsworth, 2010). Mind-wandering is also considered to be different from other cognitive behaviours because it is self-generated, spontaneous and inwardly directed. Mind wandering, according to Schooler et al. (2011) consists of two core processes: the disengaging of attention from perception (perceptual decoupling) and the ability to take explicit note of the current contents of consciousness (meta-awareness). Many researchers believe that performance on the SART can be directly attributed to this phenomenon of perceptual decoupling (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Jackson & Balota, 2012; McVay & Kane, 2009; Smallwood, McSpadden, & Schooler, 2007). During states of perceptual decoupling, attention is said to be directed away from the perception of task events to internally generated thoughts, and this redirection results in decreased processing of information relevant to an external task (Smallwood, 2013a). According to Smallwood, McSpadden, et al. (2007), perceptual decoupling is often associated with an absence of recollection of task events at a later time. They suggest the possibility that perceptual decoupling can occur before the participant is even aware that their attention has shifted from the task to internally generated thoughts. Smallwood et al. (2004) suggest that when participants in the SART are 'zoned out' or perceptually decoupled, they may fail to detect that they have made an error.

Cheyne, Solman, Carriere, & Smilek, (2009) presented a three-state attentional model of task engagement/disengagement that was applied to the SART. Based on the model, attentional disengagement during the SART can be described in three distinct states of mind-wandering:

State 1: Occurrent task inattention, involves a brief or partial waning of detailed processing of moment-to-moment stimuli leading to a disengagement of attention from some features of the task. This they referred to as ‘tuning out’. They proposed this state is reflected in the variability of RTs in the SART and is especially observed via shorter mean RTs in the trials immediately prior to go trials error trials in the SART (Manly et al., 1999; Robertson et al., 1997).

State 2: Generic task inattention occurs when attention to the general task-relevant aspects of the environment is reduced but the individual continues to demonstrate well-practiced automatic responding. This is commonly known as ‘going through the motions’ or ‘zoning out ’ and is claimed to be reflected in the SART via anticipations, i.e. responses on trials that are way too fast to be responses to the stimuli but could instead be a result of subjects anticipating the presentation of stimuli.

State 3: Response disengagement is said to involve gross behavioural indicators of mind-wandering. In this state subjects may be responsive to only the most intrusive aspects of the task environment. Response disengagement is said to be evident when subjects make omission errors, i.e. when they fail to respond to stimuli. Errors of omission have been noted to occur in the SART with both regular and random intervals between go trials and researchers have interpreted them as a break from task engagement reflecting deteriorating attention (Johnson, Robertson, et al., 2007 as cited in Cheyne et al. (2009); Manly et al. 1999).

Various other studies have also shown that performance on the SART could be an index of mind wandering across a wide range of experiments (Cheyne et al., 2009; Christoff et al., 2009; Jackson & Balota, 2012; McVay & Kane, 2009; Smallwood et al., 2007). Yanko & Spalek, (2013) argue that repeated engagement in a task will often result in gradual transition from being consciously aware and in control of one's actions, to a state where automatic processes take over our actions placing a lower demand on attentional resources. Jackson & Balota, (2012) argue that the SART's tendency to induce this shift from controlled to automatic processing is what makes it susceptible to mind-wandering.

Conversely, results from more recent studies suggest that failure to inhibit a pre-potent response rather than failure to perceive a critical stimulus is most likely the cause of SART commission errors (Carter, Russell, & Helton, 2013; Head & Helton, 2013, 2014b; Head, Russell, Dorahy, Neumann, & Helton, 2012; Helton, 2009; Helton, Head, & Russell, 2011). Stevenson, Russell, & Helton, (2011) argue that these errors are what Robertson et al. (1997) interpret as lapses of attention whereas in traditional low-go vigilance tasks decreases in detections over time (vigilance decrement) is the measure of interest. Despite participants in the SART being perceptually aware of the go stimuli (McAvinue, O'Keeffe, McMackin, & Robertson, 2005), they will often be unable to withhold a motor response (Carter, Russell, & Helton, 2013). Stevenson et al. (2011) believe that this leads to awareness of the task stimuli being (somewhat) masked by the demand exerted on motor inhibition. Consequently, commission errors may occur because participants fail to perceptually identify the critical stimulus, or because perceptual identification does not itself necessarily prevent production of the pre-potent response.

Carter, Russell, & Helton (2013) argue that the SART should not be used to measure the ability of subjects to sustain attention to external stimuli. They point out that since response inhibition is normally measured by the number of inhibition failures, i.e. inability to stop a response, errors of commission in the SART may reflect failures of response inhibition rather than lapses in sustained attention. Analogous to arguments made by Stevenson et al. (2011), Carter, et al. (2013) point out that people are aware they have made a mistake on over 99% of occasions when they respond to ago digit (McAvinue et al., 2005) suggesting participants are completely aware of the go stimuli yet apparently unable to inhibit a pre-potent motor response. Consequently, the numerous studies using the SART to measure sustained attention may likely have measured something quite different, most likely strategies that relate to inhibition of a pre-potent motor response.

Helton (2005) and Helton et al. (2009) argue that the SART may be contaminated by impulsivity, and the constant responding to neutral signals/go stimuli leads to the development of a ‘ballistic feed-forward motor program’ which causes difficulty for the supervisory attention system in its capacity to control or inhibit actions. Thus, a participant in the SART could be fully aware of the stimuli (perceptual awareness) but be unable to inhibit or disrupt this ballistic motor program. In fact, Head and Helton (2013) report that participants in their laboratory often recollect being fully aware during errors of commission on the SART while at the same time are unable to physically stop their hand from responding. Helton (2009) suggests that the SART’s response format encourages conservativeness, i.e. the participants often try to harness or control their responses; which is at odds with the view that errors result from failure to detect the presence of a relatively rare nogo stimulus.

Additional evidence for a motor decoupling perspective on the SART includes the fact that an instruction to delay responding reduces commission errors. Task instructions for the SART traditionally require participants to respond as quickly and accurately as possible, but when participants are asked to slow down (Seli, Cheyne, & Smilek, 2012) commission errors dramatically decrease. Furthermore, when participants are instructed (via an audible metronome) to delay their responses (Seli, Jonker, Solman, Cheyne, & Smilek, 2012), their commission errors again decrease.

In fact, as Helton (2009) ironically points out, even research by Robertson and his colleagues (Manly, Robertson, Galloway, & Hawkins, 1999) supports an impulsivity perspective on the SART: increase in the probability of stimuli and an increase in overall event rate leads to increased errors of commission. In other words, people are impulsive because the benefit of fast responses (impulsivity) outweighs its costs. Several studies have presented evidence indicating that the incidence of commission errors in the SART reflects response strategy rather than lapses in sustained attention (Head & Helton, 2014; Head, Russell, Dorahy, Neumann, & Helton, 2012; Helton et al., 2009; Peebles & Bothell, 2004). Helton (2009) conducted a study where participants performed global– local letter stimuli detection tasks using either the SART or the TFT (Traditionally Formatted vigilance Task, a high nogo/low go task). His findings indicated that performance on the SART changed rapidly over time and demonstrated an inverse relationship between errors of commission and correct response reaction times (identical to Roberson and colleagues' initial findings). These results were regarded as evidence of strategic slowing. Helton (2009) also argued that participants in the global–local version of the SART strategically increased their response times in order to inhibit the impulsivity which caused the commission errors. There was no comparable strategic change in a perceptually identical TFT. Helton, Weil, Middlemiss, & Sawers, (2010) interpret the Helton (2009) results as clear evidence for the role of response strategy in the determination of commission errors in the SART.

Furthermore, Helton et al. (2005) and (Helton 2009) argue that the SART is primarily a measure of speed-accuracy trade-off and response strategy. They suggest that errors of omission may be 'tactical forced rest-stops enabling enhanced inhibitory control', i.e. participants are taking a breather. Helton, Head, & Russell (2011) introduced warning cues of varying reliability into the SART to investigate its measurement characteristics and argue that if the SART is indeed a measure of sustained attention then reliable-warning cues should reduce errors of omission. But if Helton et al. (2005) and Helton’s (2009) argument is correct errors of omission should occur more frequently with reliable-warning cues because errors of omission may be tactically used to reduce commission errors. Errors of omission were in fact higher in the reliable-warning cue SART than either a no-warning cue or an unreliable-warning cue SART adding further credibility to Helton and colleagues argument that the omission errors are tactical rest stops. This also provided additional support for the perspective that the SART is a better measure of impulse control and response strategy than sustained attention.

Peebles & Bothell, (2004) proposed a computational model for performance in the SART based on the ACT-R cognitive architecture (Anderson & Lebiere, 1998) which presented two competing strategies to explain the factors that may be responsible for the speed-accuracy trade-off often seen in the SART. The ACT-R 5.0 (Anderson et al., 2004) is a version of the ACT-R cognitive architecture that adds perceptual and motor modules giving the ACT-R, visual attention and processing mechanisms, basic speech and audition capabilities, including elements of motor control to simulate interaction with a computer keyboard and mouse. Peebles & Bothell, (2004) built an ACT-R model which mimics the manner of interaction between the SART and human participants, via a mouse and text on a computer screen (see Figure 2).

The model contains two competing strategies:

I-Encode and click: The faster option, but less accurate because the model straight away clicks the mouse after detecting presentation of any stimulus on the screen.

II-Encode and check: The slower option, but more accurate because the model first checks the stimulus to ensure that it should click the mouse and only does so when appropriate

By presenting this strategy choice as an alternative explanation for commission errors, the model calls into question the role of sustained attention in the SART and provides an explanation for the speed-accuracy trade-offs that have been observed in the SART. According to Peebles & Bothell, the utilities of the two strategies (‘encode and click’ vs. ‘encode and check’) begin equal but change dynamically from trial to trial as a function of their histories of success and failure. Consequently, the likelihood of application of each strategy varies from trial to trial capturing the dependence of response times on the recency of a commission error. When the probability of error is low the ‘encode and click’ strategy builds its utility over trials making this the more likely strategy, except after an error has occurred. When the probability of error is high, then the ‘encode and check’ strategy wins out but its high time cost lessens its utility quite quickly. So probability of error has the effect of modifying the utility of each strategy over trials. In this way their model relates the likelihood of commission errors to go stimulus probability. Also, in addition to accounting for the response strategy and speed- accuracy aspects of the SART, the shift between strategies based on utility explains why subjects are unable to inhibit a response or why they are prone to impulsivity (‘encode and check’ being the predominant strategy in both cases in high go tasks).

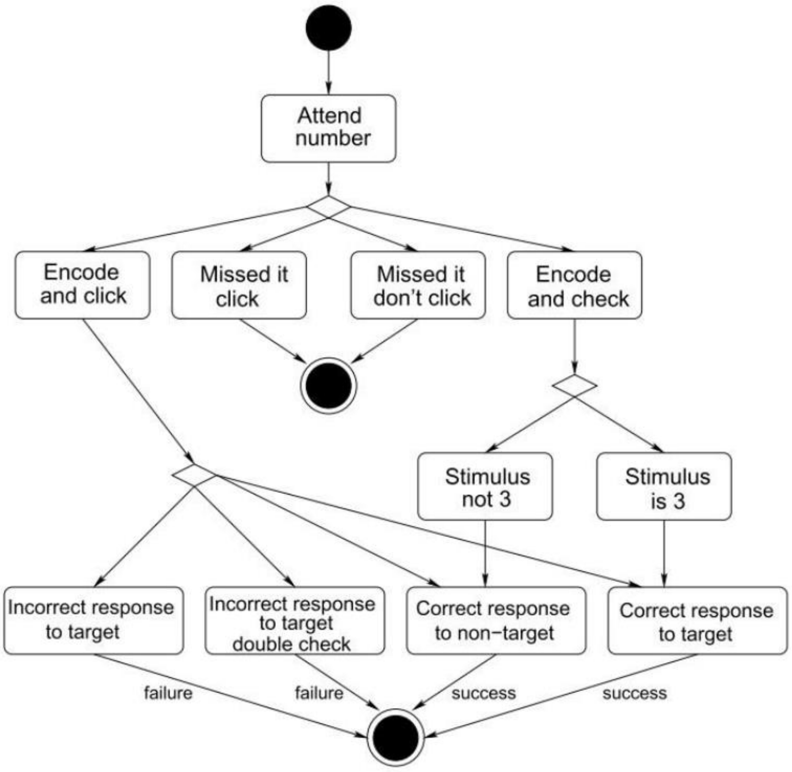


Figure. 1.2 Flow of processing in the ACT-R SART model. (Peebles & Bothell, 2004)

Subjects in the SART are given instructions which are impossible to carry out. They are told to respond as quickly to stimuli as possible without making errors on go trials. According to the model, utility is a key concept here. Finding the balance between benefits (of fast correct responses) and costs (of commission and omission errors) is paramount. In the SART where go stimuli are rare (11%) the benefits of speed far outweigh the cost of commission errors because there are few opportunities for error, consequently, participants will frequently opt for the faster 'encode and click' strategy. Probability of cost from 'encode and click' is p = 1/9 = .11. But if the probability of stimuli, is reduced for example to .50, then the opportunity for commission error increases from .11 to .50 and the cost of error from application of the 'encode and click' strategy has much higher error cost. With equal probabilities of go and no-trials, 'encode and click' will result in errors on half the trials; it is expected that 'encode and check' would be adopted much of the time.

There also exists the possibility that the two arguments in the debate may not be mutually exclusive and that errors in the SART are a result of a combination of both perceptual and motor decoupling (Seli, 2016). By the time we reach the general discussion of this thesis, I hope to convince you that one of these three possibilities/arguments hold more weight than the others.

1.4 Thesis structure

Chapter 2 to 5 investigate the consequences of shortened stimulus exposure combined with the instruction to delay responses until signalled. Chapter 6 is designed to investigate how various probabilities of trials affect the commission error rate. Chapter 7 looks at our attempt to discern what information is extracted from the digit displays in a modified version of the SART before a response is initiated. Chapter 8 reports an investigation of the impact of the location of stimuli in another modified version of the SART. The discussion will tie all the experiments together along with suggestions for future research and present a conclusion.

Chapter 2

The effects of stimulus duration and response delay on SART performance

Experiment-1

2.1 Introduction

You find yourself sitting at a traffic light at a busy intersection, patiently waiting for the lights to change from red to green. An electronic billboard in the distance switches to a new advertisement (this is your first encounter with an electronic billboard that are now common place) and for an instant you find yourself lifting your foot off the brake pedal before quickly pushing it back down. When an action is strongly anticipated and prepared what information initiates it? Are we less likely to withhold a highly prepared action when we are at the same time distracted by internally generated thoughts or mind wandering?

In the scenario above a highly prepared and anticipated action sequence (Miller, 1998) is held in readiness for immediate production the moment a critical signal (the change from red to green light) is detected but in the scenario, the readied action appears to have been initiated by a completely different and totally unrelated visual event. A plausible explanation for the corrective action in the example is that error detection and monitoring processes established that the red light was still visible and a stop reaction instruction (Aron et al., 2004; Verbruggen & Logan, 2008) was issued quickly enough to halt the action sequence required to lift the foot completely from the brake pedal and onto the accelerator. Analogous situations occur in policing, combat and hunting accidents when tragically an innocent bystander or ally is shot following abrupt change in the visual scene that is not due to entry of a foe or hunting target into the field of view (Finkbeiner, Wilson, Russell, & Helton, 2015; Wilson et al., 2013). One explanation for these kinds of unfortunate happenings is that error monitoring processes (Gehring, Goss, Coles, Meyer, & Donchin, 1993; Taylor, Stern, & Gehring, 2007) have not intervened quickly enough to prevent completion of a highly prepared action. Laboratory go/nogo tasks where the proportion of go trials is high also generate situations where people hold a much anticipated and prepared action (e.g. a key or button press response) in a high state of readiness to be initiated the instant a critical go stimulus appears. In this context too, the prepared action is inappropriately triggered by stimuli other than a critical go signal. Typically people find it difficult to resist the tendency to respond to nogo stimuli; among student populations responses are made to about 40% of nogo stimuli (Carter, Russell, & Helton, 2013; Helton, Weil, Middlemiss, & Sawers, 2010; Seli, Cheyne, & Smilek, 2012; Smallwood et al., 2007)

A fundamental question is why do people find it difficult to withhold production of a highly anticipated and prepared action when non-signalling stimuli occur? A common proposal has been that the inappropriate initiation of highly prepared actions occurs when people have lapses in attention during periods of absent mindedness or mind wandering (Cheyne, Carriere, & Smilek, 2006; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Jackson & Balota, 2012; Mcvay & Kane, 2009; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). In Chapters 2 - 5 the Sustained Attention to Response Task (SART) (Robertson et al., 1997), is adapted in an attempt to assess the role of disengagement of attention from sensory input and the task environment (perceptual decoupling) on the rate of inappropriate production of a highly prepared response.

The SART was originally developed to measure individual differences in propensity to attention lapses and specifically to assist in the diagnosis of traumatic brain injury (TBI). On each trial in the SART subjects are presented with a single randomly selected digit for 250 ms followed immediately by a mask (an encircled X) for 900 ms. Subjects are instructed to make a speeded key press response to a set of go digits (e.g. 1 - 2, 4 - 9) and not to make any response to a particular digit that has been designated as nogo (e.g. 3). Robertson et al.

argued that because the same response was required on 89% of trials and because the onset of the digit stimuli occurred regularly every 1150 ms, the key press response was highly prepared and primed (Miller, 1998) and further that it could be executed automatically without the involvement of attention. Consequently, subjects were generally able to respond appropriately to go stimuli even when their attention was disengaged. According to Robertson et al. inappropriate responses to the nogo digit (nogo or commission errors) occurred when attention to responses had momentarily lapsed. Consequently, interest focusses on the rate of nogo errors.

More recently attention lapse has been conceived by some within a broader mind wandering perspective (For reviews see Schooler et al., 2011; Smallwood & Schooler, 2015). According to this approach nogo errors occur when attention resources are directed away from the external environment and sensory input and instead channelled to internally generated thoughts and to the maintenance of a coherent stream of internal thought. When this occurs, attention is said to be disengaged from sensory input, including input generated by the task environment and subjects are describes as being perceptually decoupled. From a mind wandering perspective nogo errors are said to occur during moments when subjects are perceptually decoupled. Note according to the mind wandering explanation, nogo errors occur when attention is disengaged from sensory input whereas Robertson et al. envisaged errors occurred when subjects' attention was disengaged from the processes of response production, not from bottom-up processing of sensory input. However, acceptance that nogo errors occur due to attention lapse is not universal. Explanations that do not involve attention include speed accuracy trade-off (Head & Helton, 2014; Helton, 2009; Helton, Kern, & Walker, 2009; Seli et al., 2012), choice between fast and slow processing strategies (Peebles & Bothell, 2004) and response inhibition failure (Carter et al., 2013; Stevenson, Russell, & Helton, 2011). Head & Helton, (2013) consider these to be examples of motor decoupling emphasizing that the genesis of nogo errors lies with control of motor actions rather than lack of attention to stimuli.

In the SART digits are visible for 250 ms. But digit displays like those used in the SART can be reliably identified at exposures as brief as 50 ms (Dehaene et al., 1998). Therefore, it may be possible in the SART for subjects to be perceptually decoupled during the early part of the lifetime of a digit but for attention to be re-engaged or recoupled with perception later during the display period. Such late recoupling might allow subjects to avoid inappropriate response to a nogo digit. On the other hand, if digits are displayed for the minimum time needed for accurate identification, the opportunity to recouple attention with perception should be eliminated, or at least severely restricted, so that nogo errors should be more frequent when digits are displayed for brief durations compared to 250 ms. Experiments reported in chapters 2-4 include replications of the standard SART procedures but with digit exposures reduced from 250 ms to either 70 ms (Experiment 1) or 50 ms.

In addition to reducing stimulus duration to near minimal for identification subjects were also instructed to delay producing responses to go digits until cued at intervals ranging from 150 to 650 ms following digit onset. Only conditions where digits were visible for 50 or 70 ms were used in conjunction with response delay so that opportunities for recoupling perception and attention were eliminated or severely restricted during the display period. A person who is perceptually decoupled for the entire period that a digit is displayed should not be able to discern whether the digit requires them to make an overt response or make no response whatsoever. Therefore, if errors occur when a person is perceptually decoupled, delaying the time when responses are to be produced should have no bearing on their rate of nogo errors. To the contrary, if subjects commit nogo errors because they have chosen to prioritize speed over accuracy of response, then requiring them to delay response production should result in fewer errors because when the response is delayed stimuli can be classified[1] as go vs. nogo in time for an inappropriate response to be aborted before a key or button is pressed. Subjects were instructed to delay response production to go digits until cued by a change in thickness of the lines comprising the mask (encircled) that immediately followed every digit. As Rich et al., (2008) have pointed out in the context of visual search, reduction in errors resulting from manipulation of response delay is evidence that errors are due to motor control, not perception per se.

Others have manipulated response delay by instructing subjects to take their time and respond slowly in order to reduce errors (Seli et al., 2012), by requiring subjects to synchronize their responses to a metronome beat (Manly, Davison, Heutink, Galloway, & Robertson, 2000; Seli, Jonker, Solman, Cheyne, & Smilek, 2013) and by increasing the extent of motor movement required to execute their response (Head & Helton, 2013; Wilson, de Joux, Finkbeiner, Russell, & Helton, 2016). Generally, delay did reduce the rate of nogo errors. However, in none of these studies did stimulus duration approach the minimum needed for identification. It remains possible that subjects could recouple perception with attention at a later time during the display interval and perhaps soon enough to avoid an error response.

Seli, Cheyne, & Smilek, (2012) proposed that SART nogo errors occur because task instructions encourage people to initiate the motor program for the go response (button or key press) before they have classified the critical stimulus as go or nogo. Therefore, responses made in error to nogo stimuli should on average be faster than responses to go stimuli. Earlier Peebles and Bothell (2004) developed a two-process model of SART performance. They

---

[1] We distinguish stimulus identity and identification from stimulus classification. In the present context, a digit is identified by its numerical value but relevant to response outcome in a go/nogo situation is its classification as go vs. nogo because this determines the appropriate response action as press the button or withhold. It is possible to identify a digit but not know the action associated with it.

proposed that on each trial subjects decided (not necessarily consciously) to apply either a fast “encode and click” process or a slower “encode and check” process to the upcoming stimulus. Under the encode and check process subjects did not initiate a response until the stimulus had been classified as go vs. nogo. Under the faster encode and click process detection of stimulus onset activated the motor program for the response without regard for stimulus classification.

Both Peebles and Bothell and Seli et al. (2016) appear to propose two-process accounts of SART performance. Both include a fast process, which initiates a response prior to stimulus classification. It seems reasonable that this fast process is initiated when stimulus onset is detected. Stimulus onset occurs in the SART when the mask, which is displayed for the entire inter stimulus interval (except in the current delay experiments), is abruptly changed to a digit. It is likely then that it is this abrupt change in the visual field which initiates the fast responses in the SART. This suggests that to avoid nogo errors subjects must restrain any impulse to respond to an abrupt change in the field of view by delaying response initiation until the digit has been classified as a go vs. nogo. By this view it is the proactive control of motor acts prior to stimulus presentation (Aron, 2011) rather than the status of coupling between perception and attention at the time of stimulus presentation that determines the rate of nogo errors in the SART and perhaps other situations where it is necessary to withhold a highly prepared response. This suggests that it is important to examine the speed of error responses to nogo stimuli as well as to correct responses to go stimuli.

The first goal of Experiment 1 was to establish whether reducing stimulus duration resulted in an increase in nogo errors, as might be expected if subjects were perceptually decoupled. A second goal was to affirm that the cued delay instruction procedure did in fact delay responses. Finally, the third goal was to assess the effects of delay on the rate of nogo errors using briefly displayed stimuli that afforded little or no opportunity for the recoupling of attention with perception. To this end performance on a standard SART with 250 ms digit displays and no instructions to delay responding (250-None group) was compared to performance on, a standard SART with stimulus duration 70 ms (70-None group) and a delayed response SART, using 70 ms stimulus displays in which subjects were instructed not to respond until cued 250 ms following stimulus onset (70-250Delay group).

2.2 Method

Participants

Sixty students (45 female) participated in this experiment either for partial fulfilment of course requirements or in exchange for a $20 NZ shopping voucher. Their age ranged from 17 to 56 years (M = 20.4 years). All participants had normal or corrected-to-normal vision. The research was approved by the University of Canterbury Human Ethics Committee and students were asked if they wished not to have their data included anonymously in any published study. None elected to withdraw their data.

Apparatus

Participants were tested in groups of 4 to 10 seated at individual cubicles in a larger 35-cubicle psychology laboratory at the university. They were seated approximately 50 cm in front of an LCD computer screen (377 mm x 303 mm, 1680 x 1050 pixels, 60 Hz refresh rate) that was mounted at eye level. Their head movements were not restrained. Stimuli presentation and response accuracy and timing were achieved using E- prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002) Responses were recorded with millisecond precision using the left mouse button of a mouse connected to a serial port of an i7 PC computer (i7 processor) running Windows 7. Mobile phones were deactivated for the duration of the experiment.

Stimuli

Stimuli were the numerals 1–9 displayed in the centre of the screen in black Symbol font on a white background. Following Robertson et al. (1997) digits were displayed at font sizes 48, 72, 94, 100, or 120 pixels considered to encourage subjects to make or withhold their responses using numerical value rather than an invariant physical feature of the nogo digit. Digits were immediately followed by a black encircled X mask (Symbol font character 196) in the same size font as the digit. The 225 trials comprised 5 replications of the 9 digits at each of the 5 font sizes (9 x 5 = 45 stimuli). The stimulus presented on each trial was selected at random without replacement from the entire 225 stimuli set. The digit 3 was the designated nogo and the remaining digits were go digits so that the proportion of go trials was .89.

Procedure

Upon arrival subjects were given an information sheet explaining the task and the broad research goals and consent form to sign. Subjects were next assigned at random in equal numbers to either a standard SART group where digits were presented for 250 ms and without any instruction to delay their responses (250-None group), a group where stimuli were presented for 70 ms (4 screen refresh cycles or exactly 67 ms) again with no instruction to delay their responses to go digits (70-None group) or to a delay group where stimuli appeared for 70ms and subjects were instructed to refrain from making a response on go trials until the mask changed from regular to bold font, which occurred 250 ms following onset of a digit display (70-250Delay group).

The inter-trial interval for all groups was 1150 ms. Each trial began with presentation of a digit for 250 or 70 ms depending on group. The digit was immediately followed by the regular version of the mask which remained visible for the remainder of the trial (900 or 1080 ms for the two no-delay groups). For the delay group the regular version of the mask was visible for 190 ms and was immediately followed by the bold version of the mask for the remainder of the trial (900 ms) (see Figure 2.1).

Subjects in the two no-delay groups were instructed to respond as quickly as they could to go digits but to avoid responding whenever the nogo digit appeared. Those in the delay group were instructed to respond to go digits as quickly as they could after the mask changed but to refrain from responding to the nogo digit and never to respond before the mask changed. Subjects in all groups then completed 45 practice trials (one presentation of each digit at each of the 5 font sizes presented in random order). Accuracy feedback was displayed for 1000 ms during practice trials. Once it was established (via verbal verification) that subjects understood their task requirements subjects were presented reminder instructions and then completed the 225 main trials without interruption.

Following completion of the main trials all groups completed a 45-trial digit identification (DI) task. Digits were displayed for 250 or 70 ms depending on group. Subjects were instructed to press the corresponding number key on the computer keyboard. Unlike the main trials they were informed to take as much time as they wished to make their response. Identification stimuli comprised one presentation of each digit at each font size. The stimuli were presented in a different random order for each subject. The entire experiment took about 15 minutes to complete.

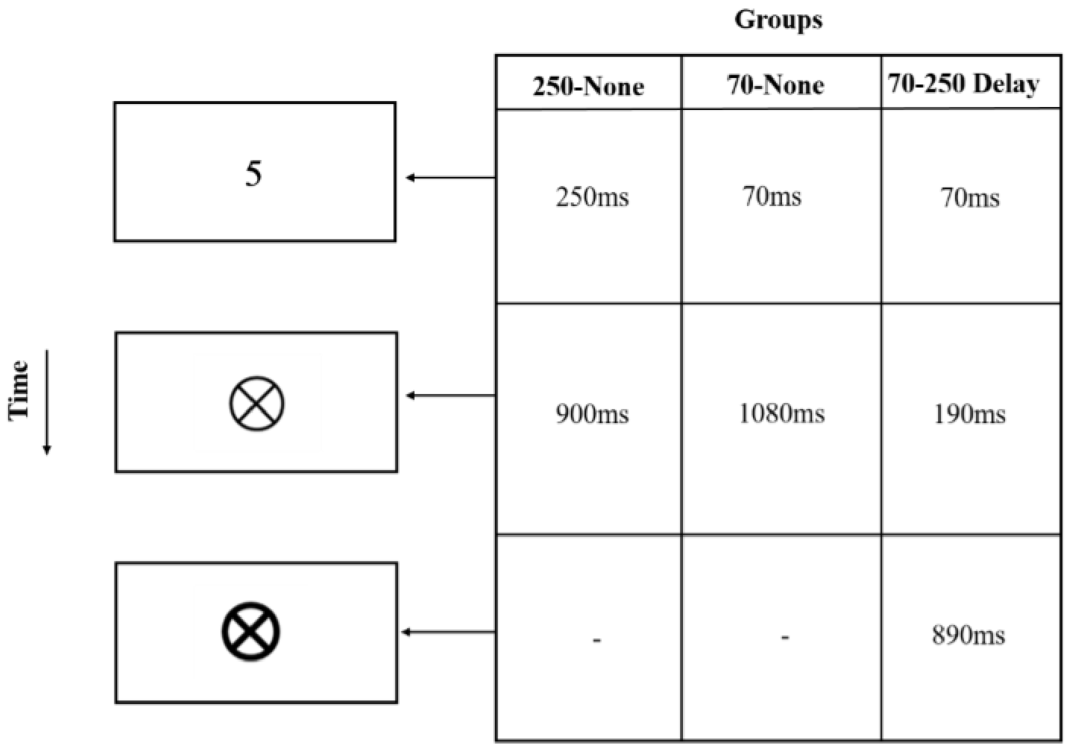


Figure 2.1. Timeline for all groups in Experiment 1

2.3 Results

Only subjects who had fewer than 25% omissions and gained at least 8/9 (88%) correct identifications in the digit identification test were included in the analyses. Accordingly, four participants were excluded from the final analysis (one from each of the two no-delay groups, and two from the delay group). Two-tailed tests are reported unless noted otherwise. Where homoscedasticity assumptions are not met *t*-test degrees of freedom have been adjusted accordingly. Non-parametric tests have been used in the analysis of omission errors because the numbers of subjects having zero omissions meant distributions were skewed.

The effect of reducing stimulus duration. The 250-None and 70-None groups were compared to assess the effects of reducing digit duration alone (See Fig. 2.2). The reduction in stimulus duration had no detectable effect on the rate of nogo errors, $t(1,36) = 0.13$, $p = .899$, $M_{\text{difference}} = 0.8\%$ 95%CI [-12.6, 14.3]. A Bayes factor analysis (Rouder, Speckman, Sun, Morey, & Iverson, 2009) with scale factor $r = 1.0$ gave an odds ratio of 4.18 in favour of the null hypothesis (retrieved from http://pcl.missouri.edu/bayesfactor, June 2018). For omission errors a Mann-Whitney *U*-test revealed that digit duration had no detectable effect on the proportion of omission errors, $U = 216.5$, $p = .297$. Also using *t*-tests no differences were detected in speed of response to go digits, $t(1,36) = -0.18$, $p = .857$, $M_{\text{difference}} = -4$ ms 95%CI [-46, 38] or speed of response to nogo digits, $t(1,36) = .17$, $p = .868$, $\mathrm{M}_{\text{difference}} = 2.8$ ms, 95%CI [-31.5, 37.2]. Correlations between RT and nogo errors were significantly different from zero for both groups but the group correlations did not differ from each other: 250-None $r = -.68$, $t(17) = -3.88$, $p = 001$; 70-None $r = -.51$, $t(17) = - 2.43$, $p = .026$; and for the difference between the group correlations, $Z_{\text{difference}} = 0.95$, $p = .343$. Overall these results indicate that reducing digit duration from 250 ms to 70 ms had no detectable effect on any of the measures of task performance.

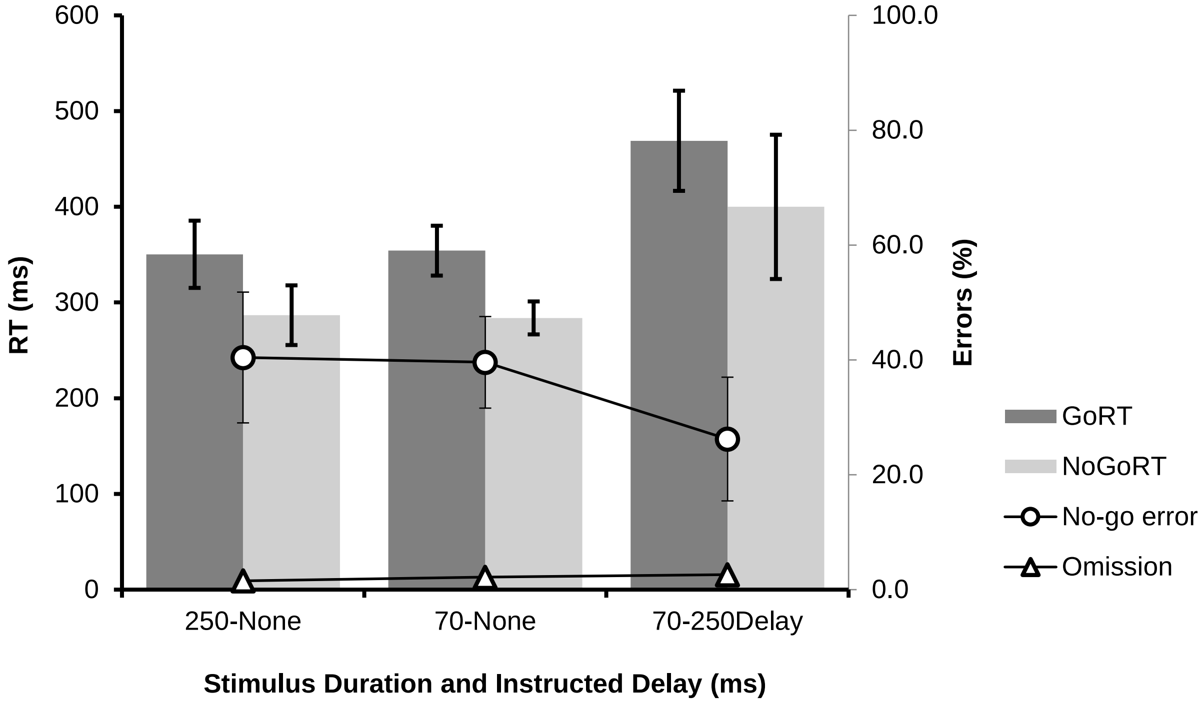


Figure 2.2. Experiment 1 mean go and nogo RTs and percent nogo and omission errors. Error bars are 95% confidence intervals.

The effect of response delay. The effects of instructing subjects to delay responses to go stimuli until cued are assessed by comparing the 70-None and 70-250Delay groups. The overall effects of delay on nogo errors and go and nogo RTs are displayed in Figure 2.2. To more fully depict the effects of delay on RTs the proportion of responses falling in 100 ms bands were computed for each subject following the procedure outlined by Seli et al. (2012). Group mean proportions are displayed in Figure 2.3. The instruction to delay response for 250 ms has increased go RTs, $t(35) = 4.21$, $p = .001$, $M_{\text{difference}} = 114$ ms, 95%CI [59, 170] suggesting that subjects observed the delay instructions. The delay instruction reduced nogo errors from 40% to 26%, $t(35) = 2.12$, $p = .042$, $M_{\text{difference}} = 13.4\%$, 95%CI [0.5, 26.2], but the delay instruction had no detectable effect on omission errors, Mann-Whitney $U = 175.5$, $p = .893$. Examination of Figures 2.2 and 2.3 indicate that the delay instruction has also increased the latency of error responses to nogo digits, *t(*18.79) = 3.16, *p* = .005, $M_{\text{difference}}$ = 116 ms, 95%CI [39, 193]. Examination of Figure 2.3 indicates that the proportion of errors with short RTs was reduced by the delay manipulation. In the absence of any delay instruction 72.6% of nogo errors had RTs less than 400 ms whereas when instructed to withhold responding for 250 ms the percent below 400 ms fell to.39.9%.

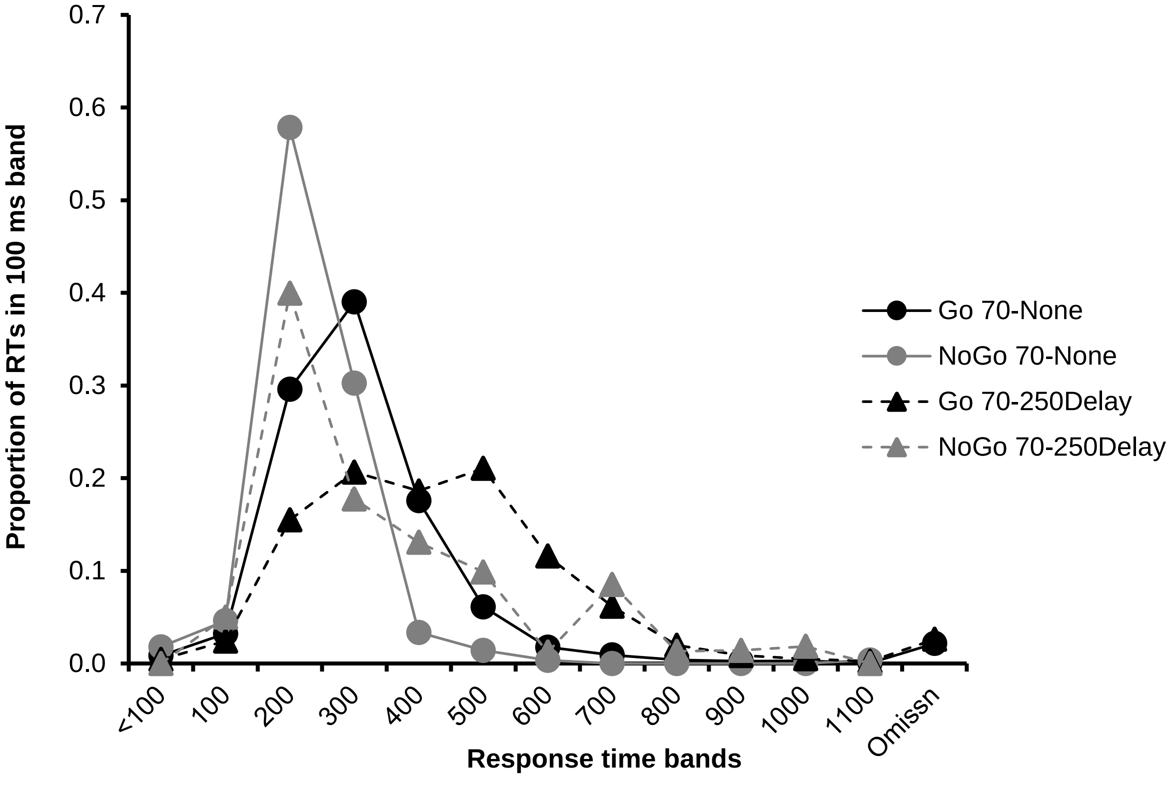


Figure 2.3. Experiment 1 proportion of RTs within 100 ms band.

Go vs. nogo RT difference. When there is no instruction to delay responding responses to nogo digits are faster than responses to go digits (see Figure 2 and compare the two solid lines in Figure 3).go RTs typically fall within a narrower range (see Figure 3). Results of paired *t*-tests between go and nogo RTs were: 250-None *t*(18) = 6.06, *p* < .001,

$M_{difference}$ = 64 ms 95%CI [42, 86]; 70-None *t*(18) = 8.09, *p* < 001, $M_{difference}$ = 70 ms 95%CI [52, 89].

2.4 Discussion

The duration of stimulus displays was reduced to near the minimum needed for accurate identification so that opportunity to recouple attention with perception (Schooler et al., 2011; Smallwood & Schooler, 2015) or recover from attention lapse and avoid inappropriate response to nogo stimuli is eliminated or at least severely restricted. Consequently, if perceptual decoupling prevents the classification of digits as go vs. nogo it is expected that nogo errors should be more common with the briefer than longer displays. The incidence of nogo errors was virtually the same with 70 ms and 250 ms displays in this close replication of the SART. Further, speed of response to go and nogo digits, incidence of omissions and correlations between nogo errors and go RT were not detectably different when digits were displayed for 70 ms and 250 ms. These results suggest that perceptual decoupling due to mind-wandering did not occur in the current experiment or if it did occur, recovery or recoupling of attention with perception was not evident when digits were displayed for the usual 250 ms. Another possibility is that the involvement of attention in extracting the identity of the digit stimuli has little to do with the genesis of nogo errors in high go tasks such as the SART.

The effect on nogo errors of the combination of minimal stimulus duration and an instruction to delay responding until cued was also explored. When stimulus duration is minimal, delaying response production should be of no assistance on those trials when a subject is perceptually decoupled. This is because with brief stimulus displays there is no opportunity, or at most very little opportunity, for subjects to extract stimulus classification if it had initially been missed due to the subject being perceptually decoupled. Reduction in nogo errors contingent upon manipulation of response delay is evidence that nogo errors can occur for reasons other than perceptual decoupling. When stimuli were displayed for 70 ms introduction of the instruction to delay response production until cued 250 ms after stimulus onset resulted in a reduction in nogo errors from near 40% to near 26%.

An alternative to perceptual decoupling as the cause of nogo errors is the possibility, outlined in the introduction, that nogo errors occur in a context where subjects have high expectation that a strongly prepared action will be appropriate the moment an abrupt change is detected in their visual field. According to this view nogo errors are more likely when subjects fail, before the stimulus is presented, to take control of their actions and delay initiation of a highly prepared motor response (Aron, 2011) until classification of stimulus as go vs. nogo has occurred. This view is consistent with the finding that error responses to nogo stimuli were close to 65ms faster than responses to go stimuli for both 70 ms and 250 ms duration displays and it is also consistent with the finding that requiring subjects to delay response production significantly reduced the rate of inappropriate responding to the nogo digit.

Chapter 3

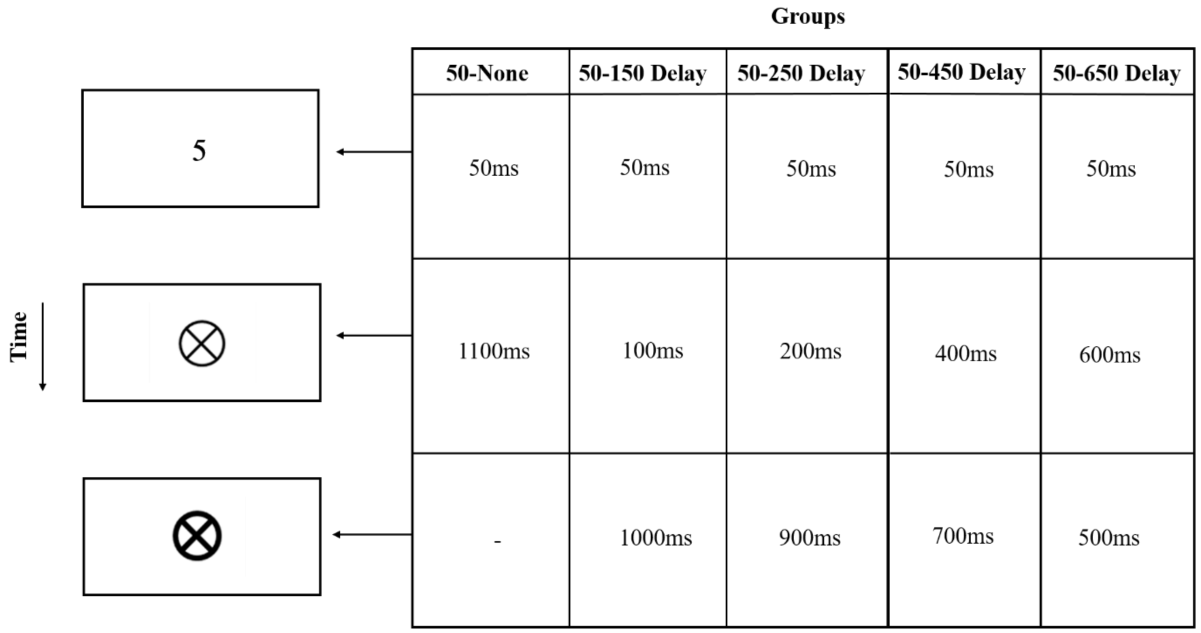
The effects of duration of response delay on SART performance

Experiment-2

3.1 Introduction

The results from Experiment 1 establish that while reducing stimulus duration from 250 to 70 ms had no detectable effects on SART performance the combination of brief stimulus display with an instruction to delay responding until cued reduced nogo errors from near 40% to 26%. Although unlikely 70ms may still provide some opportunity for recoupling had perception and attention been decoupled at the time of stimulus onset. Further, Seli et al., (2013), who also demonstrated a reduction in nogo errors when responses were delayed, directed their subjects to delay for longer than 250 ms. Consequently, in Experiment 2 digit duration was reduced to 50ms and different groups of subjects were instructed to delay responding until cued 150, 250, 450 or 650 ms after stimulus onset (see Figure 3.1). The delays were influenced by (Seli et al., 2013) and 50 ms digit duration was achieved by reducing digit displays from 4 to 3 screen refresh cycles (pilot work indicated that stimuli were not identifiable when visible for 2 screen refresh cycles or 33 ms).

As previously explained, instruction to delay responding until cued should not reduce the rate of nogo errors among subjects who were perceptually decoupled during stimulus presentation and this will be true regardless of the delay period. On the other hand, if nogo errors occur because people fail to prevent initiation of a highly prepared and strongly anticipated response when abrupt change occurs in their visual field, an instruction to delay responding until cued is expected to bring about a reduction in nogo errors, provided the delay period is effective in extending response times beyond any threshold necessary for digit classification as go vs. nogo. But extending the delay interval beyond the classification threshold should have minimal further advantage. Contrary to this prediction (Seli et al., 2013) found fewer nogo errors with longer delay. However, in their experiment digits were displayed for 250 ms and rather than delay response until cued their subjects were required to actively synchronize responses with the regular beat of a metronome.



Groups

50-None	50-150 Delay	50-250 Delay	50-450 Delay	50-650 Delay
50ms	50ms	50ms	50ms	50ms
1100ms	100ms	200ms	400ms	600ms
-	1000ms	900ms	700ms	500ms

Figure 3.1. Timeline for all groups in Experiment 2.

3.2 Method

Ninety nine students (79 female) participated in this experiment in conditions similar to those in Experiment 1. Their ages ranged from 17 to 52 years (M= 19.6 years). All had normal or corrected-to normal vision and none had participated in Experiment 1. Altogether, Experiment 2 was a replication of Experiment 1, but now the stimulus duration was reduced to 50 ms (3 refresh cycles) and in addition to a no delay condition different groups were instructed to delay responding until cued 150, 250, 450, or 650 ms after stimulus onset. In all other respects stimuli, masks, instructions, and procedures were identical to those of Experiment 1.

3.3 Results

Only subjects who had fewer than 25% omissions and who gained at least 8/9 (88%) correct identifications in the identification test were analysed. A total of 12 participants were excluded from the final analysis, 1 from the no delay group, 2 each from the 150 and 250 ms delay groups, 4 from the 450 ms delay group and 3 from the 650 ms delay group.

***The effect of reducing stimulus duration*.** As expected from Figure 3.2, contrasts between the 250None group from Experiment 1 and the 50-None group revealed no significant difference in mean percent of nogo errors, *t*(36)= 0.0, *p* = 1.0. Bayes factor analysis, scaling factor *r* = 1.0, gave an odds ratio in favour of the null hypothesis of 4.2 (retrieved from http://pcl.missouri.edu/bayesfactor, June 2018). Omissions were, however, more common with the shorter digit duration, (1.5% vs. 5.1%) Mann-Whitney *U* = 248.5, *p* = .046. RTs did not differ with digit duration, *t*(36) = .414, *p* = .681. For comparison of RT distributions see Figure 3.3 panel A. The proportion of RTs within each 100ms band was found for each subject. Group means are reported in Figure 3.3. The distributions of go RTs are similar across digit durations (250-None, 70-None and 50-None). Distributions of nogo RTs (Figure 3.3 panel B) are also similar for all digit durations although there is more inter-subject variation among the proportions of longer nogo RTs as evidenced by the larger confidence intervals in Figure 3.3B Reducing digit duration to 50ms did not result in a significant change to the correlation between go RTs and proportion of nogo errors, 250-None *r* = -.68, 50-None *r* = -.42, $Z_{\text{difference}}$ = -1.33, *p* = .18.

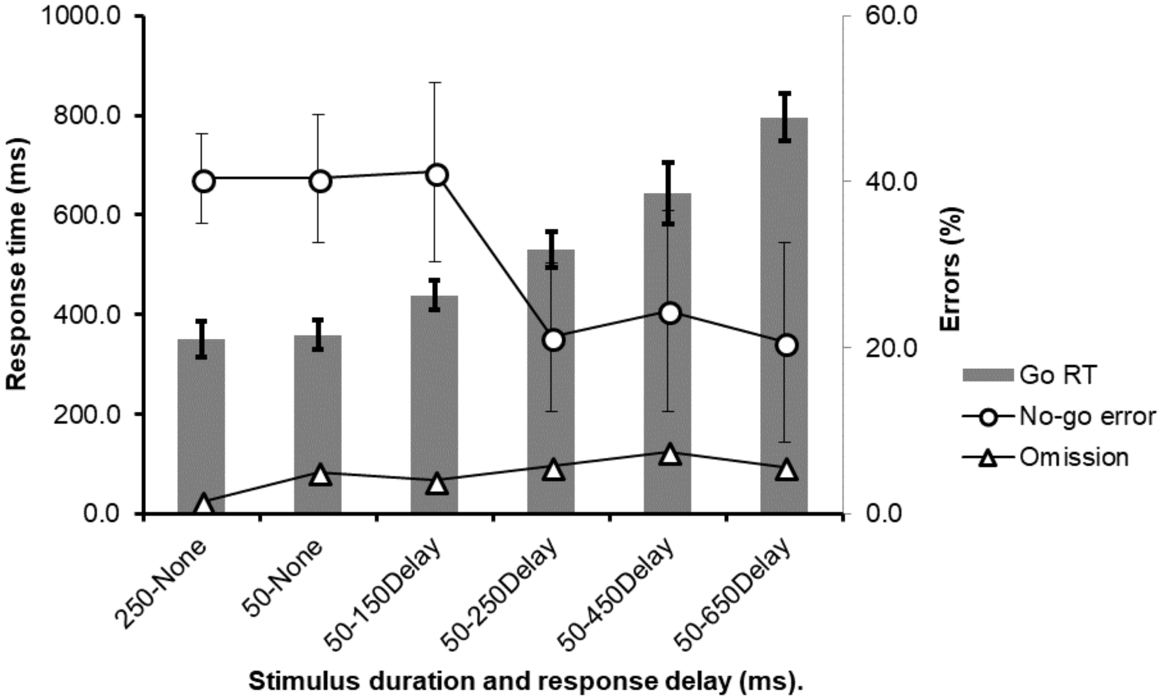
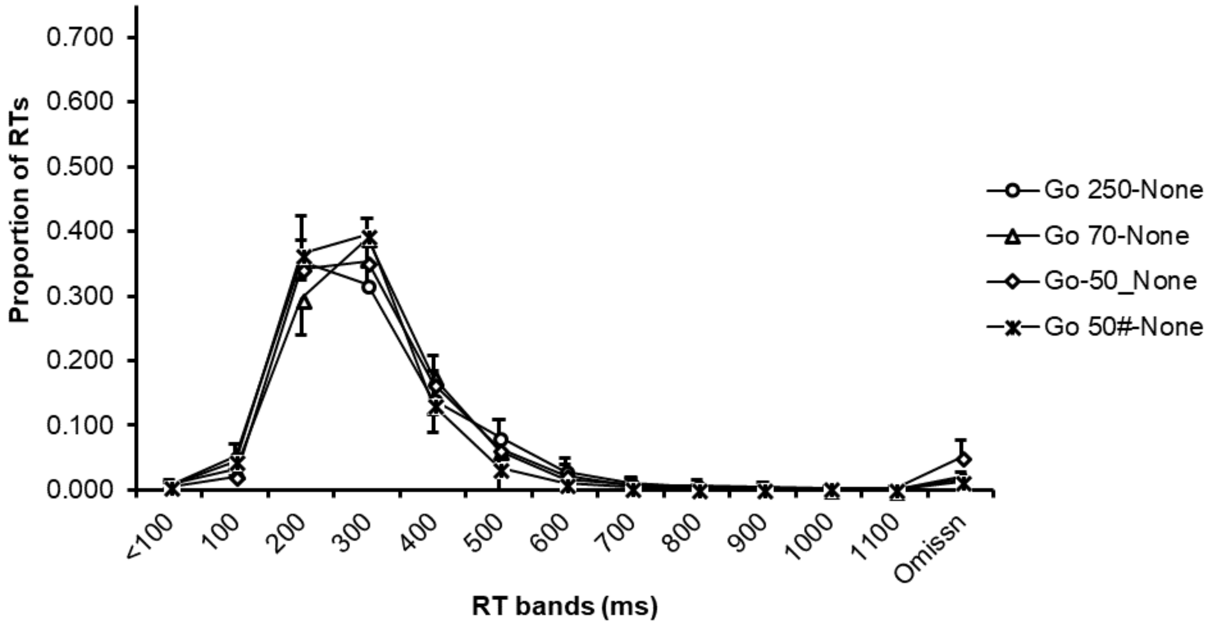


Figure 3.2. Experiment 2 mean RTs and percent nogo and omission errors. Error bars are 95% confidence intervals.

A. Go RTs



B. No-go RTs

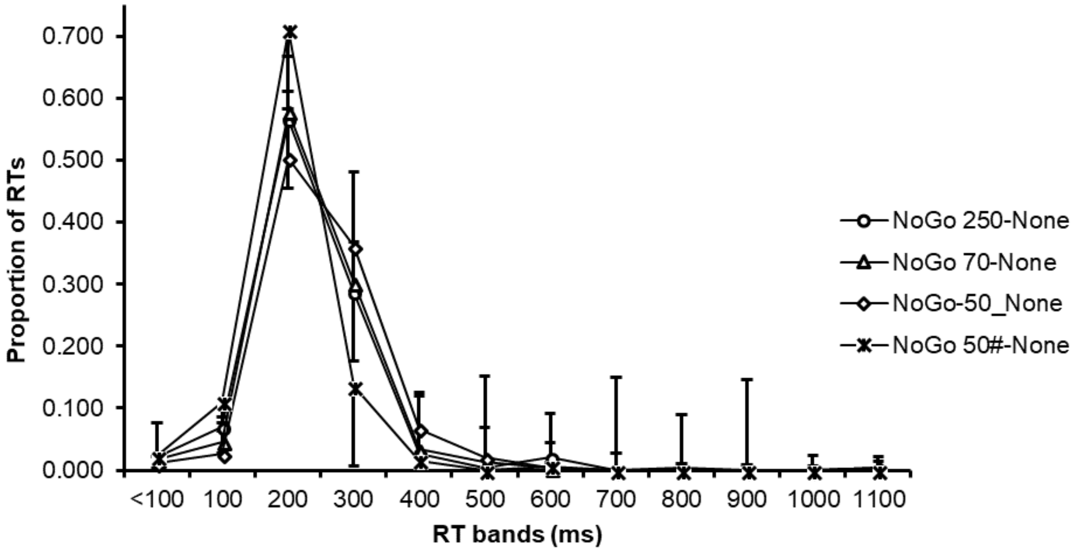


Figure 3.3. Experiment 2 and 3 No-delay groups, proportion of RTs within 100 ms band **A)** RTs, **B)** go RTs. Error bars are 95% confidence intervals.

The effect of response delay. The effects of response delay can be seen in Figure 3.4. Percent nogo errors for the 50 ms digit duration groups were treated by a one way ANOVA (Levene test established group variances were not different), $F(4,82) = 4.58$, $p = .002$, $\eta_p^2 = .183$. This was followed by a set of Repeated contrasts (None vs.150, and delays of 150 vs.250, 250 vs 450, 450 vs.650). Only the 150 vs. 250 delay contrast was significant, $p = .005$, $M_{\text{difference}} = 19.8\%$, 95%CI [6.2, 33.5], all other contrasts $p > .59$. A minimal delay of 250 ms appears necessary to produce a significant reduction in nogo errors when digits are displayed for 50 ms. Greater delays did not produce additional reduction in nogo errors below the 21.3% level achieved with a 250 ms delay. A Kruskal Wallis one-way analysis for independent groups revealed no detectable difference in omissions between the different response delay groups, $H(4) = 3.60$, $p = .462$, although as noted, omissions are more common with the shorter display duration. RTs were treated by an independent groups ANOVA (Levene's test revealed no significant difference in group variances). Overall RTs increased with delay, $F(4, 82) = 76.7$, $p < .001$, , $\eta_p^2 = .79$. Repeated contrasts revealed that the difference in RT was significant for all pairs, all $p < .005$.

Distributions of RTs and nogo RTs are presented separately for each delay condition in the in panels in Figure 3.4. RTs are distributed about modes that increase with length of delay indicating that subjects have attempted to observe the delay instructions. In conditions where there is no instruction to delay and when the cue to respond occurs 150 ms or 250 ms after stimulus onset, error RTs cluster around modes in the 200-299 ms band (no-delay group) or in the 300-399 ms band (150 and 250 ms delay groups). With no-delay or delays of 250 ms or less, responses to nogo errors are typically faster than responses to go stimuli. However, when the cue to respond occurs 450 ms or 650 ms after digit onset, errors do not appear to cluster about a single mode. With delays of 650 ms error RTs are most common in the 100-199 ms band and the 800-999 ms range but unlike the modes with no-delay or shorter delays, these modes are greater not less than the modes for go RTs. With longer delays subjects who do not respond to the first abrupt change during a trial (i.e. stimulus onset) appear on some occasions to respond to the second abrupt screen change of the trial (i.e. mask change).

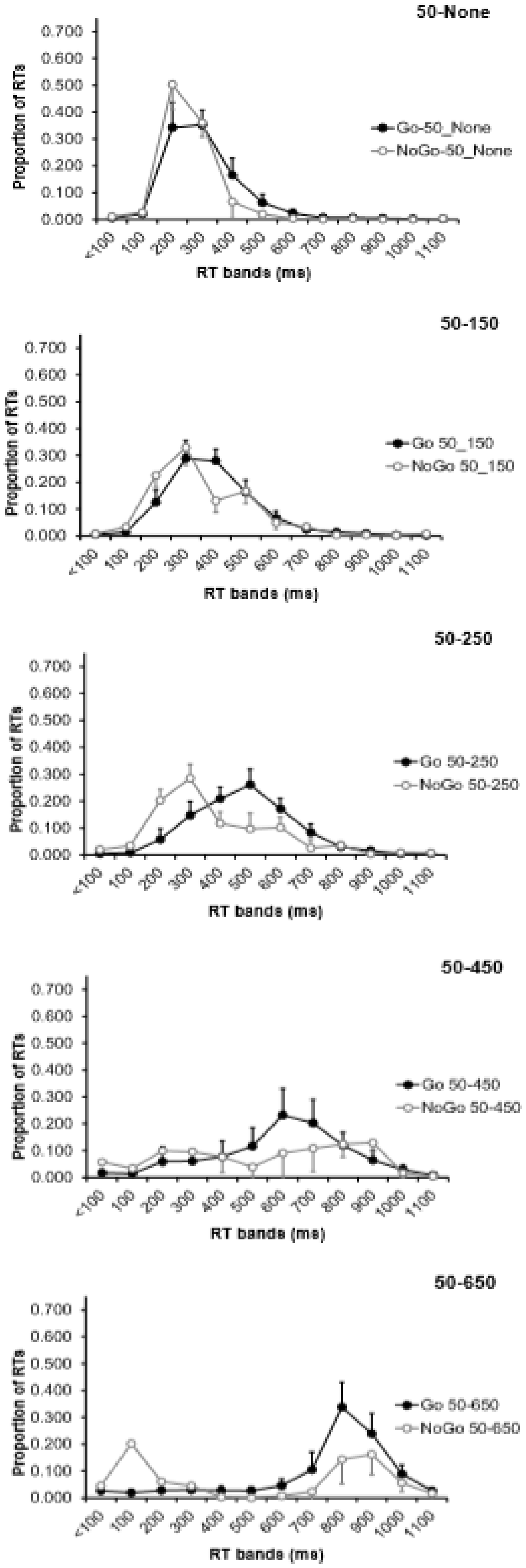


Figure 3.4 Experiment 2 Proportion of RTs in 100 ms bands for various delay groups. Error bars are 95% confidence intervals.

Go vs. nogo RT difference. As in the no delay conditions in Experiment 1 responses made in error to nogo stimuli by the 50-None group (M = 306 ms) were faster than responses to go digits (M = 359 ms), $t(18) = 6.43$, $p <.001$, $M_{\text{difference}}$ = 53 ms, 95%CI [36, 70].

3.4 Discussion

When digits are visible for just 50 ms and there is no instruction to delay responding the probability of nogo errors is indistinguishable from a standard 250 ms SART, i.e. around 40%. Also, speed of response to go and nogo digits, and correlations between nogo errors and go RT were not detectably different from those obtained with 250 ms digit displays. However, the incidence of omission errors was greater with the reduced digit duration. This may be because on a few occasions subjects realized they had been unable to identify the briefly displayed digit and therefore made no response. If classification of a digit as go vs. nogo is missed due to the subject being perceptually decoupled during the brief digit displays no opportunity exists to recouple attention with perception. Therefore, if nogo errors occur because of mind wandering such errors will be more common with brief than the usual 250 ms display durations used with the SART. As in Experiment 1 no detectable difference was found in nogo error rates between 250 ms and brief displays. Overall these results suggest that perceptual decoupling did not occur in the current experiment or if it did occur, recovery does not occur within the typical 250 ms duration of stimuli characteristic of the SART. These results suggest that decoupling of attention from perception is unlikely to be the prime cause of nogo errors in high go tasks such as the SART.

When minimal display duration was coupled with a signal to delay response production until cued the incidence of nogo errors declined from around 40% to near 22%, but only when the delay interval was 250 ms or greater. As previously explained, error reduction consequential upon a combination of minimal stimulus display durations with delayed response production is not predicted from perceptual decoupling.

Current results differ from those reported by Seli et al., (2013) and Manly, Davison, Heutink, Galloway, & Robertson, (2000). Both Seli et al. and Manly et al. required subjects to respond in synchrony with a metronome tone. Neither study reported any reduction in nogo errors when the tone followed digit onset by 400 ms or less. In contrast significant reduction was found with a 250 ms delay instruction in both Experiments 1 and 2 reported here. But go RTs obtained by Seli et al. were considerably faster for comparable instructed delays than those obtained in the current experiments. For example, when instructed to synchronize responses with a tone occurring 400 ms after digit onset Seli et al. found mean go RT to be less than 350 ms. By contrast in the current experiment an instructed delay of 450 ms resulted in a mean go RT of 643 ms and with a 250 ms instructed delay mean RT was 531 ms. The shorter latencies reported by Seli et al may reflect the differing task requirements. Under an instruction to synchronize, responses occurring before the tone may represent legitimate estimates of the precise moment of arrival of the tone as they were instructed to do. Under instructions to delay responding until cued responses made before the cue are in breach of instructions. Therefore, although the instructed delays may appear the same in the current and synchronization tasks go RTs are likely to be longer among subjects instructed to delay responding until cued than among subjects asked to synchronize.

The crucial variable associated with whether nogo errors are reduced by any requirement to delay response production does not appear to be the duration of the instruction but the effect the instruction has on the actual time at which responses are produced. Examination of the results reported by Manly et al. (2004) and Seli. et al. (2013), together with those from the current experiments, show that reduction in the rate of nogo errors occurs only when go RTs exceed 500 ms or where go RTs are at least 100 ms longer than comparable no delay control conditions (this also appears true of Head & Helton, 2013).

One interpretation of the results from Experiments 1 and 2 is that nogo errors are avoided in high go SART-like go/nogo tasks when subjects are able to prevent triggering a response to abrupt change in the visual field. In tasks where there is no manipulation of response delay nogo errors typically occur when subjects respond quickly. If subjects can be induced by an experimental manipulation to withhold producing a response until sufficient information has accrued from the display to classify the stimulus as go or nogo their responses will be slower overall and responses to nogo stimuli less common. What caused the reduction in nogo errors in the current experiment was not increase in go RT per se but the effectiveness of a delay manipulation in restraining the impulse to respond to stimulus onset. Delaying response production for longer allows more time for stimuli to be classified as go vs. nogo and hence for the appropriate respond or withhold response action to be determined.

In the current experiments the minimum nogo error rate achieved was around 21%. This is, similar to that reported by Seli et al. 2012 where subjects were instructed to slow down in order to reduce errors. However, Seli et al. (2013) achieved rates as low as 5% among subjects instructed to synchronize responding to a metronome beat. Stimulus durations were 250 ms in both experiments. Therefore, it seems likely that it is the nature of the tasks (synchronization vs. instruction to slow down and cued delay), rather than digit duration that is responsible for the difference in nogo error rates between experiments. Studies using extent of movement as the instrument of delay also result in lower nogo errors than those reported here (down to 2%) (Head & Helton, 2013; Wilson et al., 2018). In the delay condition in these experiments stimulus onset provides the cue to begin an extended response process. The time provided by the execution of an extended movement also allows extraction of information regarding stimulus classification to accrue concurrently with response production processes. If evidence of a nogo stimulus accrues sufficiently early a reactive stop instruction may halt the response process before a button press has been executed resulting in avoidance of a potential nogo error (Aron, 2006, 2011; Verbruggen & Logan, 2008).

An important question is how does instructing subjects to delay producing a response until cued assist them to withhold immediate response to the abrupt scene changes that occur with stimulus onset? Results reported here suggest there may be more than one answer to the question. Examination of the distributions of nogo RTs (Figure 3.4) suggests delay instructions coupled with response cues behave differently when the delay is brief and when it is longer. With no-delay or delays of 250 ms or less error responses are typically fast (there are very few long RT error responses) and faster than the mode of go responses. With delays of 450 ms or longer, error responses tend not to be clustered around a single mode but occur at almost any point during a trial. Further, with longer instructed delays modes of error RTs tend to be greater than the corresponding mode for go RTs. The introduction of cues also doubles the number of scene changes a subject experiences; changes now occur at stimulus onset and perhaps less conspicuously when the mask is changed. When there is no instruction to delay responding, subjects in the current experiments can safely initiate their response to 89% of scene changes (go trials), but when a cue is introduced the number of scene changes experienced doubles and it becomes safe to respond to only 45% of the changes. The cost of using scene change over stimulus classification as the effective stimulus for response production is increased when cued delays are introduced; consequently, subjects may prioritize a slower “check” process over a faster process that does not involve checking stimulus identity (Peebles & Bothell, 2004).

There is another difference between current results and those of Seli et al. (2013): beyond the minimum delay interval necessary to bring about a reduction in nogo errors increasing the delay interval produced no additional reduction in nogo errors in the current experiment but increasing delay from 600 to 800 ms in the synchronization task used by Seli et al. reduced errors from 15% to 5%. However, in the current experiment it appears subjects who resisted responding to abrupt change that accompanied digit onset sometimes went on to respond to abrupt change occurring at cue onset when the mask changed. This may have been sufficient to cancel the opportunity for more accurate stimulus classification afforded by longer delays.

Chapter 4

The role of the mask in controlling effective stimulus duration

Experiment-3

4.1 Introduction

So far it has been argued that reducing stimulus duration to the minimum necessary for stimulus identification prevents the re-engagement of attention should subjects have been perceptually decoupled during the 250 ms stimulus duration typically employed in the SART. However, in the previous experiments it may have been possible for subjects to recover from perceptual decoupling if the opportunity for recovery existed after stimulus offset and before the delayed response cue. Recovery may be possible even with 50 ms digit exposures if subjects have access to the display during the delay interval in some temporary visual memory system such as iconic or visual sensory memory (Keogh & Pearson, 2011; Sperling, 1960). To prevent continued access to the digit display after it ceases to be visible on the screen and therefore to prevent any advantage that may accrue from recovery from perceptual decoupling, it is necessary to immediately follow the display by an effective mask (Enns & Di Lollo V, 2000; Kouider & Dehaene, 2007). In Experiment 3 the encircled X was replaced by a structured pattern mask (see Figure 4.1) which incorporates features shown to restrict post-display processing. This mask is comprised of line segments that are designed to replicate the contour properties of the digits used as stimuli. This is done so that when the mask is overlaid on any of the 9 digits the stimulus is rendered invisible.

The experiment involved a between groups design with no delay and 450 ms delay groups in which 50 ms digit displays were followed by the structured pattern mask. To show that the pattern mask without delay behaves indistinguishably from the standard encircled X mask used in Experiments 1 and 2 performance in the no delay condition is compared with the corresponding no delay group from Experiment 2 (i.e. comparison of the 50-None group with a 50#-None group where # denotes pattern mask). To assess the effects of a delay following a pattern mask compared to the standard encircled X mask Experiment 3 includes a 50#-450Delay condition which is contrasted with the 50-450 condition from Experiment 2.

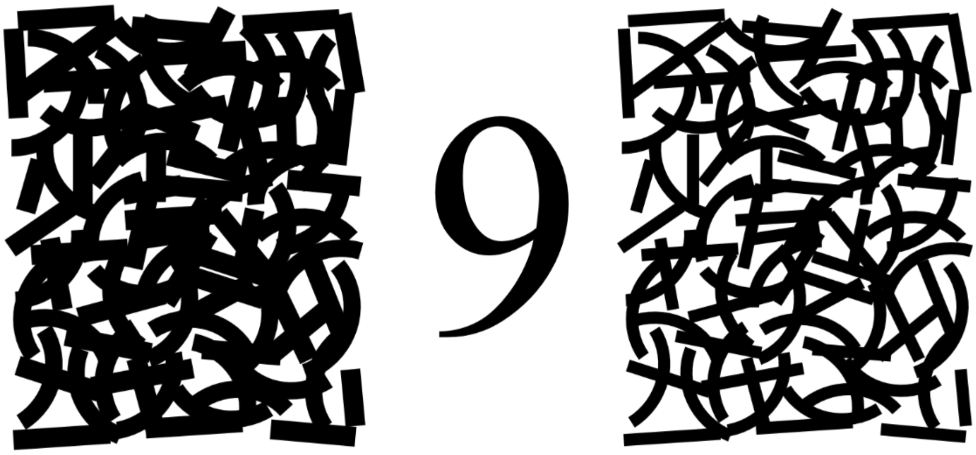


Figure 4.1. The thick and thin versions of the structured mask and digit 9 used in Experiment 3. Size scaling is preserved.

4.2 Method

Thirty-nine students (25 female) were randomly assigned (19 to the no delay group) in conditions similar to those in Experiment 1. Their ages ranged from 18 to 51years (*M*= 21.9 years). All had normal or corrected-to-normal vision and none had participated in Experiment 1 or 2. For the 50#-450 delay group the thick pattern mask changed to the thin pattern mask 450 ms after digit onset. All digits were displayed in 120 pt. Symbol font. The relative size of masks and digits is displayed in Figure 4.1.

4.3 Results

One participant from the delay condition achieving only 44% correct digit identifications was excluded from the final analysis. Percent nogo errors and go and nogo RTs and omission errors for Experiment 3 and relevant conditions from Experiment 2 are presented in Figure 4.2.

Comparison of traditional and pattern masks, no delay. The 50-None and 50#-None groups were compared. No differences were detected in nogo errors, $t(1,36) = .316$, $p = .753$, $M_{\text{dfference}} = 1.89\%$, 95%CI [-10.2, 14.0]. The odds ratio in favour of the null hypothesis was 4.03 (retrieved from http://pcl.missouri.edu/bayesfactor, June 2018) using r = 1.0). No differences were detected in go RTs, $t(1,36) = 1.513$, $p = .149$, $M_{\text{difference}} = 26.6$ ms, 95%CI [-9.1, 62.3]. However, at 50 ms stimuli durations omissions were less common when digits were followed by the pattern mask (1.3%) than traditional mask (5.3%), Mann-Whitney U =99, $p = .017$. The correlation between go RT and percent nogo errors was $r = -.41$, $t(17) = -1.86$, $p = .07$, which compares with $r = -.42$ from the 50-None group of Experiment 2. The two correlations were not significantly different, $Z_{\text{difference}} = .022$, $p = .982$. The change from traditional to pattern mask appears to have had no detectable effect on go RTs, the frequency of nogo errors or the correlation between go RT and commission errors but it has reduced omission errors relative to the standard mask.

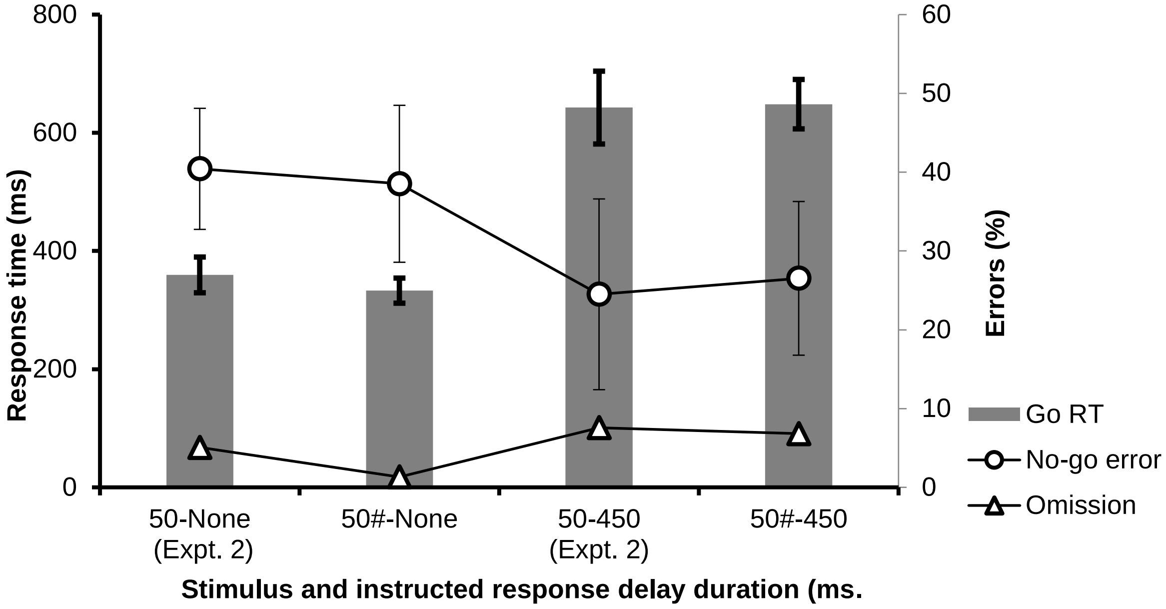


Figure 4.2 Experiment 3 mean RTs and percent commission and omission errors. Error bars are 95% confidence intervals**.**

The effects of delay and mask type. This involves comparing the two groups having no delay with the two 450 ms delay groups in a 2 (mask type) x 2 (delay) design. Percent nogo errors and go RTs were treated by separate Mask (traditional vs. pattern) x Delay (None vs 450ms) ANOVAs. Go errors were significantly fewer with a delay of 450 ms compared to no delay, $F(1,69) = 8.92$, $p = .004$, $\eta_p^2 = .114$, $M_{\text{difference}}$ 14.0%, 95%CI [4.6, 23.3]. Neither the mask main effect nor the mask x delay interaction effects approached significance, both F less than 0.2, both $p > .67$, both $\eta_p^2 < .003$. RTs were significantly greater with delay, $F(1, 69) = 253.9$, $p <.001$, $\eta_p^2 .= 786$, $M_{\text{difference}} = 299$ ms, 95%CI [262, 337]. Mask type had no effect on go RTs and the effect of delay was not moderated by mask type; the delay main effect and interaction effects were not significant, both F less than .40, both $p > .58$, both $\eta_p^2 < .012$. To assess omissions across the 4 groups an independent samples Kruskal Wallis test was performed. Group omission errors were found to differ significantly, $H(3) = 14.9$, $p = .002$. However, while under no delay omissions were fewer with the pattern mask, no detectable difference in omissions was found between the two masks at 450 ms delay, Mann-Whitney $U = 150.5$, $p = 961$. In summary, instruction to delay responding until cued 450ms after digit onset increased go RTs by 300ms regardless of mask type and reduced nogo errors equally for the traditional and pattern masks. The effect of mask on omissions is less clear.

Go vs. nogo RT difference- No Delay Group. Similarly to Experiments 1 and 2 error responses were made more quickly to nogo digits ($M = 259$ ms, $SD = 29$ ms) than correct responses to go digits ($M = 333$ ms, $SD = 94$ ms), $t(18) = 7.94$, $p < .001$, $M_{\text{difference}} = 74$ ms, 95% CI [54, 93]. See Figure 3.3 which also includes the 50#-None results.

4.4 Discussion

In this experiment the effectiveness of the traditional encircled X mask was assessed by comparing performance when it was replaced by a structured pattern mask possessing properties known to curtail stimulus processing (Enns & Di Lollo V, 2000; Kouider & Dehaene, 2007). Reassuringly no differences were found in the rate of nogo errors, go RTs or correlation of nogo errors and go RTs between the traditional and pattern masks using stimuli that were displayed for 50 ms. The pattern mask did however result in fewer omission errors than the encircled X mask with 50 ms digit displays. Also, as in experiments 1 and 2 error responses to nogo digits were faster than responses to go digits and by a comparable amount.

In the current experiment the opportunities for perceptually decoupled subjects to recouple attention were eliminated by immediately following the 50 ms digit displays with a structured pattern mask. Because a perceptually decoupled subject cannot recouple attention and perception during the delay interval, introducing a delay should produce the same proportion of nogo errors as a comparable control condition having no delay instructions. Contrary to perceptual decoupling, the instruction to delay responding for 450 ms again produced a significant reduction in nogo errors from near 40% to approximately 25% when delay was introduced.

Further, the reduction in nogo errors observed in Experiment 3 is not detectably different from that in Experiment 2 where stimuli were followed by the encircled X mask. These results indicate that the traditional mask, acted effectively in terminating processing of the digit stimuli, giving confidence in results from Experiments 1 and 2. The encircled X mask and digits were matched for font size in Experiments 1 and 2. Typically in SART experiments, the mask is larger and the same for all digit font sizes creating the possibility that the encircled X mask used in the current experiments may have been more effective than the mask traditionally employed with the SART. Small digits overlaid by a large X may remain identifiable due to the relatively large empty areas compared to overlay by a similarly sized X.

Chapter 5

Inappropriate production of highly prepared acts: Perceptual decoupling due to mind wandering or lack of motor control?

General Discussion- Experiments 1 to 3

Incidents of friendly fire in policing, combat and hunting where a colleague or companion is shot suggest that people have difficulty withholding a highly prepared (Miller, 1998) and anticipated action when abrupt change occurs within their visual field (Wilson, Head, & Helton, 2013; Wilson, Head, de Joux, Finkbeiner, & Helton, 2015). In laboratory go/nogo tasks with a high proportion of go trials subjects respond inappropriately to over 40% of nogo signals (Carter et al., 2013; Helton et al., 2010; Seli et al., 2012; Smallwood et al., 2004), again suggesting people have difficulty withholding production of a highly prepared action when abrupt visual change occurs. This inappropriate response production is frequently considered to occur during moments of attention lapse (Cheyne, Solman, Carriere, & Smilek, 2009; Cheyne et al., 2006; Cheyne, Carriere, & Smilek, 2009; Jackson & Balota, 2012; Manly, Robertson, Galloway, & Hawkins, 1999; Schooler et al., 2011; Smallwood, McSpadden, & Schooler, 2007). More recently such errors have been ascribed to mind wandering and to occur at times when attention and perception are decoupled. (Smallwood et al., 2004; Smallwood, McSpadden, et al., 2007; Smallwood, O'Connor, Sudbery, & Obonsawin, 2007; Smallwood & Schooler, 2015). An opposing view is that the inappropriate production of a highly prepared action results from a lack of motor control not disengagement of attention from perception (Head & Helton, 2013). The major goal of Experiments 1-3 was to determine the roles of perceptual decoupling and motor control in the genesis of commission errors in the SART. Stimulus durations were reduced to levels near the minimum necessary for accurate identification and subjects were instructed to delay response production until cued by a change in the appearance of the mask that followed each stimulus.

When perceptually decoupled for the entire duration that a stimulus is displayed it should not be possible to discern the go vs. nogo classification of the stimulus and therefore perceptually decoupled subjects will not know whether a response is required or inappropriate. However, with the SART, digit stimuli have typically been displayed for considerably longer than the minimum time needed for digit identification (Dehaene et al., 1998) raising the possibility that subjects may be able to recouple attention and perception later in the display period but in time to avoid a response and hence nogo error. Reducing the duration of digit stimuli to the minimum needed for accurate identification should eliminate or severely restrict opportunities for recoupling attention and perception. Consequently it is expected that the rate of nogo or commission errors would increase with reduced stimulus duration. In none of the three experiments reported here did the probability of nogo error increase when stimulus duration was reduced from 250 ms to near minimal levels (50 to 70ms). Further, to exclude the possibility that the traditional encircled X mask did not effectively terminate digit displays, in Experiment 3 the traditional mask was replaced with a specially tailored structured mask that possesses properties known to effectively terminate the digits (Breitmeyer, 2007; Enns & Di Lollo V, 2000).go errors and RTs were comparable across masks indicating that the traditional mask was effective in our experiments where importantly digit and mask font size were equated (typically in published studies the mask was larger on most trials so that mask and digit were less overlapping). In light of these results we were led to conclude that either perceptual decoupling did not occur in our experiments or, if it did occur, recoupling of attention with perception did not happen soon enough within the duration of 250ms displays to affect the rate of nogo errors.

When stimuli are displayed briefly, requiring subjects to delay response production should have no effect on the rate of nogo errors. This is because if the correct response outcome has not been ascertained by the end of the display duration, a perceptually decoupled subject will have no opportunity to determine appropriate response action during the delay interval. Over the three experiments subjects were instructed to withhold making any response until cued by a change in the mask which occurred between 150 and 650 ms following digit onset. In the three experiments response delay produced a reliable reduction in nogo errors provided the delay period was at least 250 ms. Overall, the probability of responding to a nogo digit fell from around .40 in the three no-delay control conditions to less than .25 in conditions where the instructed delay was 250ms or greater.

Others have also manipulated response delay in various ways; by instructing subjects to slow down in order to avoid errors (Seli et al., 2012), by synchronizing response production with the onset of a tone occurring at known intervals after stimulus onset (Manly et al. 2004; Seli et al., 2013), and by manipulating the extent of response movement (Head & Helton, 2013, Wilson et al., 2018). In none of these was stimulus duration reduced to the minimum needed for stimulus identification. Consequently, reduction in nogo errors could have occurred because the delay gave subjects opportunity to recouple attention with perception later in the stimulus display period and hence avoid inappropriate response production. However, because we found that reducing stimulus duration had no effect on the incidence of nogo errors it seems unlikely that the reduction in nogo error rate reported by Seli et al., Head and Helton and Wilson et al. is due to recoupling attention with perception. Rather it seems that it is the delay in initiating a response that is instrumental in reducing nogo errors. Parallel findings and conclusions arise in visual search. When target absent displays greatly outnumbered target present displays (low target prevalence) response delay has been found to eliminate miss errors in “pop out” search (Rich et al., 2008). This situation is similar to a high go task except on each trial search involves a choice between two responses rather than a choice between production of a single response and withholding all overt action. Rich et al. used the elimination of miss errors to rare stimuli under the response delay condition to reject stimulus processing explanations for miss errors (comparable to nogo errors in a go/nogo task) in favour of proposals ascribing errors in low target prevalence situations to an inability to control the highly expected act of responding target present).

Because a person who is perceptually decoupled during stimulus presentation should not benefit from delaying production of their responses reduction in nogo errors produced by manipulating the time of response production is evidence of trials where perceptual decoupling has not occurred. While a reduction in nogo errors to a little less than 25% of all nogo trials was found in the current experiments others report levels as low as 5% and even 2% (Seli et al., 2013, Wilson et al., 2018). If we accept the low rate of nogo errors reported in these studies is due to delay and not the late recoupling of perception with attention during the display period, then it seems that perceptual decoupling may occur on as few as 5% or even 2% of nogo trials in these experiments.

Another result that appears to be problematic for perceptual decoupling is the finding that subjects in the SART know on over 99.9% of occasions when they inappropriately respond to a nogo digit (McAvinue et al., 2005). For subjects to know when they have committed an error they must have extracted stimulus classification (go vs. nogo) from the display and compared this with their actual response. It seems unlikely such linking is possible when a person is perceptually decoupled and disengaged from sensory input including the task environment. Relatedly in visual search where targets were rare and target absent responses strongly anticipated subjects also knew when they made a mistake; allowing them opportunity to immediately indicate their errors halved miss errors when targets occurred on only 10% of trials (Fleck & Mitroff, 2007).

Consistent across the four no-delay groups in the current experiments was the finding that inappropriate responses to nogo stimuli were made significantly faster than responses to go stimuli. In agreement with proposals by both Seli et al. (2012) and Peebles and Bothell (2004) the faster responding to nogo than go stimuli suggests that nogo errors occur when subjects initiate their response quickly in response to stimulus onset and before establishing the go vs. nogo status of a stimulus. Since abrupt change from mask to digit occurs at stimulus onset in these experiments it is suggested that the effective stimulus for fast responding is abrupt visual change. But it is not only on nogo trials that a response will be initiated by abrupt visual change. Stimuli were randomly sequenced, subjects could not predict whether an upcoming stimulus would be a go or a nogo stimulus and therefore subjects should be just as likely to respond to an abrupt change when a go as when a nogo stimulus was presented. Consequently, the distribution of RTs to go stimuli likely contains a mix of fast responses initiated by abrupt change, and slower responses made after extraction of stimulus go vs. nogo classification.

Together the results reported above are consistent with the proposal that to avoid making a nogo error in high go situations a subject must have activated processes that restrain the tendency to respond automatically or reflexively when abrupt visual change occurs in their field of view. These restraining processes must be in place prior to presentation of the nogo digit or soon enough after presentation to terminate an initiated response process if one had begun. Also, the response restraining processes must induce a delay in response initiation that is sufficient to allow determination of the go vs. nogo status of the stimulus and this classification of a stimulus must occur in time to stop a response should one already be in progress. This explanation for inappropriate production of highly anticipated response actions in high go tasks such as the SART and friendly fire and similar situations places the ultimate origins of inappropriate responding in the realm of motor control (Head & Helton, 2013), not perception. Without response delay, perception of the stimulus as go or nogo occurs too late to prevent inappropriate production of a highly anticipated and prepared response. This is in line with original account offered by Robertson et al. (1997) for the SART. They deliberately linked attention to response, not to perception, when they named their newly developed task the Sustained Attention to Response Task.

The consequences of abrupt visual change have been explored in the context of attention to locations using 2-choice tasks and multi-element displays (Weissman, Roberts, Visscher, & Woldorff, 2006; Yantis & Hillstrom, 1992). Abrupt change that marks the entry of a new object into the visual field attracts attention to its location and choice responses are made faster to immediately following stimuli appearing at locations to which attention has been directed prior to stimulus appearance. These findings would appear to have little application in the present experiments and to the SART task because the tasks are so different. Displays in the present experiments and the SART do not parse into multiple elements; only one stimulus is visible at a time. Further the single stimulus always appears in the same location and change from stimulus to mask also always occurs at that location. Selection of one location out of a competing set is not involved here. Further, for each subject the moment of stimulus onset, mask onset, and mask change is highly predictable; within each experiment various ISI's are constant in the experience of subjects. Stimulus location and timing are more variable in friendly fire and hunting contexts. Another difference is that absence of focus of attention to a location increases response time in multi-elements display, but in the context of go/nogo tasks lapse of attention (which many believe to be the cause of nogo errors) results in faster responses. In the present experiments it is not that abrupt visual change attracts attention to a location, rather it is proposed that abrupt change of object at a known location and expected time causes instant production of a highly prepared or anticipated action unless procedures that delay its production have already been activated.

Our conclusion is that inappropriate production of a highly prepared action such as a key press to a nogo stimulus in a high go task like the SART, or activation of a gun trigger in friendly fire accidents, is rarely if at all in the first instance, due to the decoupling of attention from perception. Rather inappropriate production of a highly prepared and anticipated action occurs because people find it difficult to refrain from impulsively or reflexively producing the action immediately abrupt visual change is detected. By this view, to prevent inappropriate production of a highly prepared action it is necessary to have in place, prior to the abrupt change, processes which successfully delay initiation of the action until the go vs. nogo classification of the stimulus has been extracted and is available to guide action. The ultimate cause of inappropriate action is not the decoupling of perception from attention but lack of motor control. The present experiments leave open the possibility that attention lapse or disengagement of attention, whether due to mind wandering or for other reasons, reduces the ability to refrain from responding to abrupt visual change. In life threatening situations such as combat, policing and in previous periods in human evolution, rapid production of a prepared and anticipated response to any abrupt visual change is more likely to be life preserving than delaying the action to allow identification of the cause of the change as benign or dangerous. This perspective raises many questions for further research. What determines the level of preparedness of an action? Can multiple different actions be simultaneously held in high states of readiness? Would people also respond impulsively to abrupt auditory or other sensory change? What is the role of attention in controlling the tendency to respond to abrupt change? Are some people more prone than others to respond to abrupt change?

Chapter 6

The effects of the proportion of go trials on SART performance

Experiment -4

6.1 Introduction

In this experiment the proportion of go trials was varied from a low of 50% to 100% go trials. Several theories of SART performance predict an increase in nogo errors and a speeding of responses to go stimuli with increasing proportion of go trials. Robertson et al. (1997) proposed that the probability of attention lapse, and hence nogo error, increased the longer the run of uninterrupted of go trials. Since the average run length is greater the higher the proportion of go trials it follows that errors will become more likely as the proportion of go trials increases. Robertson and colleagues also suggested responses became more automatized and faster with increasing run length. Average run length is greater the higher the proportion of go trials giving rise to faster go responses the higher the proportion of go trials. Similar predictions can be derived from perceptual decoupling (Cheyne et al., 2009; Smallwood et al., 2004; Smallwood & Schooler, 2015) except that instead of withdrawal of attention from responses, attention is said to be disconnected from perception, again resulting in greater frequency of commission error and faster responses to go stimuli when go prevalence is higher.

The account offered by Peebles and Bothell (2004) does not involve attention. Instead subjects make a choice between a fast click strategy and a slow check strategy on each trial. With the click strategy responses are initiated without regard to the go vs. nogo classification of digits. The slower check process does verify digit classification before making a response or withhold as appropriate. On each trial the strategy having greater benefit relative to cost is adopted. When 90% of trials are go trials the fast process can be applied because the benefit of speed outweighs the smaller cost of relatively rare error; speedy response on every trial regardless of digit classification incurs cost, at most, on 10% of trials. However, when 50% of trials are nogo the cost of error from adopting the fast strategy could result in error on as many as 1 in every 2 trials; the higher the proportion of go trials the lower the cost of error from adopting the fast process. RTs on go trials are expected to decrease with increasing proportion of go trials because more frequent application of the fast process results in proportionately more of the responses to go trials being generated by the fast process. The choice mechanism relies on past history of success (from respond when go, withhold when nogo), not current digit classification. Therefore, to the extent that the fast process has success it will be applied on go trials.

The theories of SART performance outlined above all predict that error responses will be made more quickly to nogo digits than responses to go digits. But what are the expectations for the effects of go prevalence on speed of response on nogo trials? For Peebles and Bothell (2004) and the proposal that subjects initiate the response process upon detection of abrupt visual change, the prediction is clear. If all nogo errors result from application of the same fast strategy or in response to detection of abrupt change, then error RTs should be the same regardless of the proportion of go trials.

6.2 Method

Participants

A total of 406 introductory psychology students (289 female) at the University of Canterbury served as participants. Their ages ranged from 17 to 49 years (M = 19.8 years). All had normal or corrected-to-normal vision. The research was approved by the University of Canterbury Human Ethics Committee and students were asked if they wished not to have their data included anonymously in any published study. None elected to withdraw their data.

Apparatus

Participants were tested in the context of their regular weekly laboratory session, which contributed to course credit. They were seated approximately 50cm in front of an eye-level LCD computer screen (377 mm x 303 mm, 1680 x 1050 pixels, 60 Hz refresh rate) in individual cubicles in a larger 36-cubicle psychology computer laboratory. Their head movements were not restrained. Stimuli presentation and response accuracy and timing were achieved using E- prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002). Responses were recorded using the spacebar on a keyboard connected to an i7 PC computer running Windows 7.

Stimuli

Following the normal procedures of the SART stimuli were the numerals 1–9 displayed in the centre of the screen in white Symbol font at sizes 48, 72, 94, 100, or 120 pixels on a black background. They were immediately followed by a white encircled X (the mask) in the same size font. The digit 3 was the designated nogo and the remaining digits were go digits. Digits were displayed for 250 ms, with mask visible for 900 ms.

Procedure

Subjects in each laboratory class were randomly assigned to one of ten groups. Groups varied in proportion of go trials as follows: Group 1 50%, Group 2 64%, Group 3 74%, Groups 4 to 9 78% to 98% in 4% increments and Group 10 100%. Digit and font size were determined randomly within the provision that the requisite number of go and nogo trials occurred in each block of 50 trials. Subjects completed 5 blocks of 50 trials in which they were instructed to respond as quickly and accurately as possible by pressing the spacebar to go digits and to make no response to the nogo digit 3. Only the first response made during the 1150 ms interval between the onset of a digit and offset of the mask was recorded. All subjects, regardless of prevalence group, completed 16 practice trials, 8 go and 8 nogo with go digits and font size selected at random (within the constraint that the number of go and nogo trials was equal). Practice trials were identical to the main trials except that visual feedback informing subjects of the correct action (press the space bar or make no response) was displayed at the end of the trial interval for 1000 ms following both a failure to respond to a go digit (omission) and production of a response to a nogo digit (nogo or commission error). No feedback was provided during the main trials. The experiment took about 15 minutes to complete.

6.3 Results

Two subjects were excluded from the analysis. One in group 2 (64% go trials) recorded a response on all 250 trials. One subject in Group 8 (94% go trials) registered a response for only 20% of go trials. Because go and nogo trials appeared in equal numbers during practice results from the first 50-trial block were not included in the following analyses. The first block provided opportunity for subjects to become familiar with the proportion of go trials applying to them. All analyses involve blocks 2-5. Error rates are presented in Figure 6.1.

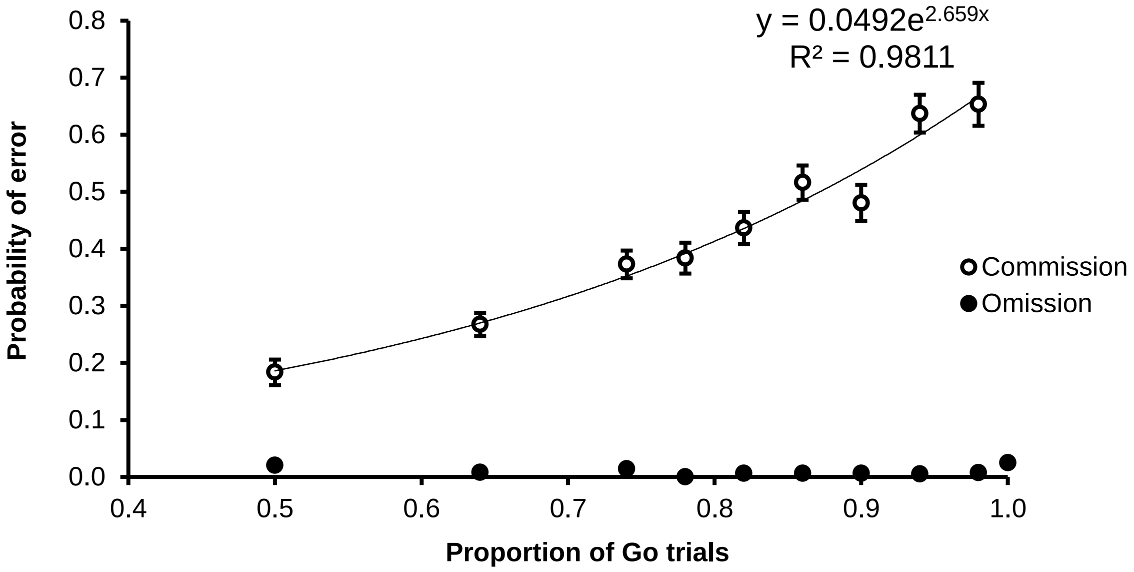


Figure 6.1. Mean commission and median omission errors as a function of proportion of trials. Error bars are 95% Confidence Intervals.

Omissions: Subjects rarely failed to respond to go digits. Overall median probability of making an omission error was .009. A Kruskal Wallis analysis revealed that groups did differ in their rate of omissions, $H(9) = 29.06$, $p = .001$. Follow up analyses using a Stepwise step down procedure (Field, 2013, pp. 244-246) revealed that Groups 2-9 comprised a homogeneous group that was distinguishable from Group 1 (*Mdn* = .020) and Group 10 *Mdn* = .025), Groups 2-9, $H(7) = 7.75$, adjusted $p = .422$.

Commissions Errors: Subject nogo error probabilities were treated by a between Groups (Excluding group 10 where all trials were go trials) ANOVA to assess the effects of proportion of go trials on error rate. Probability of commission error increased with proportion of go trials, $F(8, 353) = 25.3$, $p = < .001$, $\eta_p^2 = .364$. When various functions were fit to the means plotted in Figure 6.1 exponential and power functions produced the highest R^2 values (98) as illustrated in the figure.

The effects of proportion of go trials on RTs: Two subjects in Group 8 (94% trials) were excluded from the analysis of RTs because they had no commission errors and hence no RTs for nogo trials. Mean go and mean nogo RTs were found for each subject. Mean group go and nogo RTs are displayed in Figure 6.2. Subject mean RTs were treated by a mixed Groups (Groups 1-9) X go vs.nogo ANOVA. RTs decreased with increasing proportion of go trials, $F(8,351) = 22.2, p < .001, \eta_{\mathrm{p}}^2 = .336$. Responses to go stimuli were also slower than error responses to nogo stimuli, $F(1, 351) = 336.6, p < .001, \eta_p^2 = .490, M_{\mathrm{Difference}} = 52$ ms, 95%CI [49, 55]. The groups X go vs. nogo interaction was not significant, $F(8, 351) = 1.48, p = .165, \eta_p^2 = .033$. Trend analyses of group differences could not be conducted using ANOVA because intervals between groups in proportions of go trials are not equal. However, trend lines were fitted to the group means in Figure 6.2. The best fitting lines, second order polynomials are displayed on the figure.

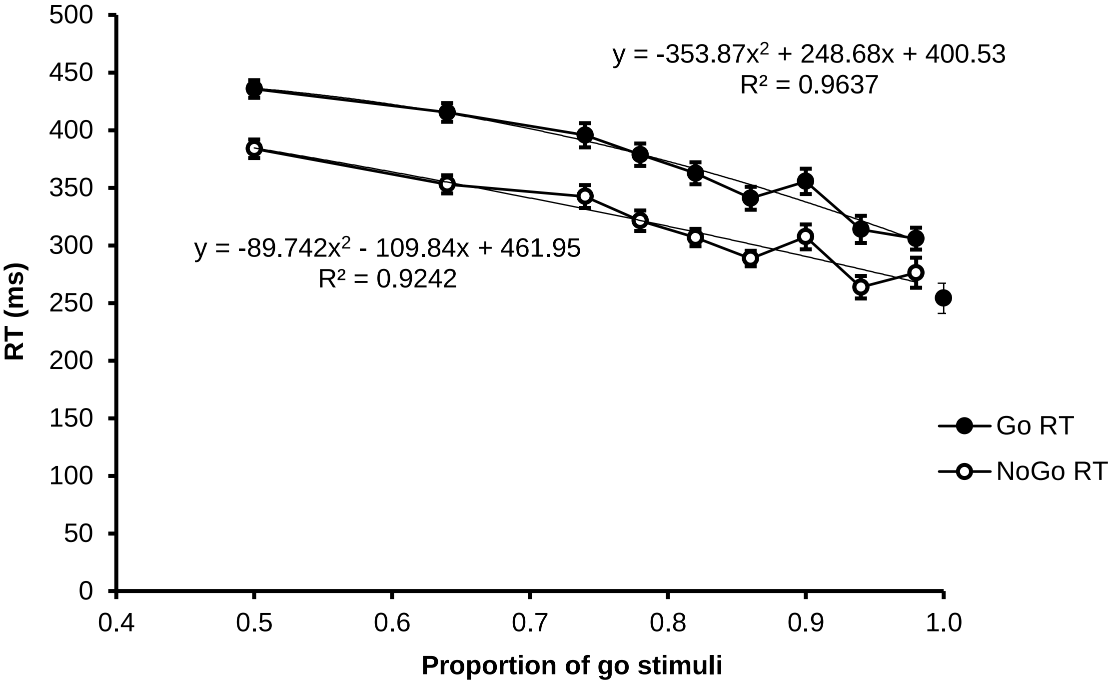


Figure 6.2. Go and nogo RTs as a function of proportion of go stimuli. Error bars are 95% confidence intervals

6.4 Discussion

As predicted by all theories of SART performance outlined in the introduction, the probability of commission error increased with increasing proportion of go trials. The theories made no prediction about the exact relationship between proportion of go trials and rate of nogo error but results indicate a positively accelerating relationship. Also, as predicted go RTs fell with increasing prevalence of go trials this time with the rate of decrease itself steepening with higher go prevalence. Also in accord with predictions, error responses to nogo digits were faster by about 50 ms than responses to go digits, a figure which compares with Experiments 1 to 3. However, unexpectedly speed of response to nogo digits also decreased with increasing proportion of go trials and at a rate not detectably different from that of go trials.

This is an important result. It is not predicted by the Peebles and Bothell (2004) model which postulates a choice between a fast click and a slower check process on each trial. Nogo errors result from application of the fast process. If the same fast process is responsible for nogo errors no matter the proportion of go trials, nogo RTs should be constant or at least very similar across variations in go prevalence. Similarly, if nogo errors occur when subjects respond to the occurrence of abrupt visual change, not digit classification, it is reasonable to expect speed of response to abrupt visual change also to be independent of the proportion of go trials experienced by a subject. The finding that nogo RTs decrease with increasing proportion of go trials is inconsistent with all proposals incorporating the assumption that nogo errors are produced by an identical process requiring the same completion time regardless of the proportion of go trials.

The proposal that errors occur when subjects respond to abrupt visual change or adopt a fast process (Peebles & Bothell, 2004) can be accommodated. If subjects use abrupt change as the signal to initiate their response they may also be able to alter the speed with which the response action or fast process is implemented; confident actions may be executed with more force and faster. Another possibility is that subjects may delay the initiation of the response or fast process, the extent of the delay being affected by the proportion of go trials. Both delay and reduced speed of implementation provide extended opportunity for concurrent processes of stimulus extraction to proceed. When the chances of a nogo stimulus occurring are low (high go prevalence) little benefit accrues from extending opportunities for stimulus extraction; the outcome is likely to be respond. Therefore, in high go situations, subjects will be more inclined to respond with more force and faster, or not to delay initiation of the response process when they detect abrupt change.

Cheyne et al. (2009) proposed that omissions indicate instances when a subject is in a state of response disengagement, the most severe of three levels of disengagement of attention from the task that they put forward. But trials where subjects failed to respond at all were quite rare. The conclusion to be drawn from the present results is that that subjects rarely suffer this most pronounced degree of mind wandering, and when they do the duration of disengagement is typically confined to a single trial. Further omissions appear stable over a range of go probabilities from .64 to .98. This is counter to the argument (Manly et al., 1999) that repeated responding leads to attentional disengagement. By their argument if omissions are reflective of attention disengagement we would expect a monotonic increasing relation between go probability and omissions. Helton and colleagues (Head & Helton, 2013; Helton, 2009; Helton, Kern, & Walker, 2009) have suggested that omissions occur when subjects rest from the demands of frequent responding. By this argument omissions are also expected to increase with the proportion of go trials. Contrary to these views omission errors were stable across the range of go probabilities from .64 to .98. An omission could occur if an anticipatory response on a particular trial occurred during the response interval for the previous trial, where it was not recorded (due to prior response during the interval) and it was perceived as applying to the current digit. In other words, omissions could occur when subjects attempt to synchronize responding with the onset of a stimulus regardless of its go vs. nogo status.

Chapter 7

An investigation of the effect of flanker stimuli in the SART

Experiment-5

7.1 Introduction

The experiments reported in Chapters 2-4 showed reducing stimulus duration to near the minimum necessary for identification had no detectable effect on the incidence of nogo errors, but instructing subjects to delay responding until cued did significantly reduce the rate nogo errors. Also error responses to nogo digits were typically faster than responses to go stimuli. To explain these findings it was proposed that subjects have a strong tendency in high go situations to initiate a prepared response as soon as they detect abrupt change in their field of view. Response production is thought to be initiated before the go vs. nogo status of the stimulus is extracted. While it may be still be possible to ascribe nogo errors to incomplete perceptual processing of stimuli, it is important to note that incomplete extraction of stimulus information is not considered due to lack of attention or limitation of processes related to perception; rather the response process is triggered prematurely and independently of stimulus analysis. By this view the prime cause of nogo error has to do with inadequate motor control not perceptual processes involving the extraction of information. The current experiment further explores the role of perceptual processing in the in the genesis of nogo errors in high go tasks such as the SART by using a flanker task (Eriksen & Eriksen, 1974) in conjunction with manipulation of the proportion of go trials or prevalence of go trials.

In the 2-choice flanker task subjects respond to target stimuli that are flanked by so-called distractors. On different trials the distractors are associated either with the same response as the target (congruent trials) or a different response action (incongruent trials). The dependent variable of interest is the difference in choice RT between incongruent and congruent displays. When incongruent RTs exceed congruent RTs their difference is described as a flanker congruency effect (FCE) (Eriksen & Eriksen, 1974; Lehle & Hübner, 2008; Sanders & Lamers, 2002). If a FCE also occurs in a go/nogo task RTs on go trials to incongruent go displays will be reliably longer than RTs to stimuli flanked by congruent stimuli. In the present context if subjects identify go stimuli before initiating a response they should display a flanker congruency effect (FCE) such that go targets flanked by congruent digits will be responded to more quickly than to go targets flanked by incongruent digits. On the other hand, if subjects begin their response before identifying the digits there should be no difference in response time between congruent and incongruent go trials.

Additionally, the magnitude of FCE found in go/nogo tasks is predicted to decrease the higher the proportion of go trials. The rate of responding to nogo stimuli in SART-like tasks has been found greater the higher the proportion of go trials (Experiment 4, Wilson, Finkbeiner, de Joux, Russell, & Helton, 2016). Peebles and Bothell (2004) emphasise the importance of the costs of error and benefits of speed. When go and nogo stimuli are equally likely the cost of responding on every trial is a 50% error rate, but when 90% of trials are go trials choosing to respond on every trial has a maximal error rate of just 10%. If subjects take time when go and nogo trials are equally likely, to extract sufficient information to avoid nogo errors, then response times to congruent go stimuli should be faster than to incongruent go stimuli, producing a FCE similar to that found for 2-choice tasks. On the other hand, when go prevalence is high (90%) and where subjects are far more inclined to initiate their response rapidly, perhaps when an abrupt screen change is detected, there should be little if any difference in RT between incongruent and congruent go trials. In short, the higher the proportion of stimuli the smaller the flanker congruency effect expected.

It is also worth considering the role of flankers on performance on nogo trials. According to advocates of perceptual decoupling inappropriate response to a nogo stimulus occurs because perception was decoupled from attention during the time a stimulus was visible. Consequently, it is unlikely that congruency should have any bearing on the rate of nogo errors or the speed of error response. Similar predictions follow from proposals put forward by Robertson and colleagues (Manly et al., 1999; Robertson et al., 1997) who suggest no go errors occur when lack of attention allows production of an automatized response. Also, the proposal that abrupt screen change, not stimulus identity, sparks response initiation leads to the prediction that nogo errors and speed of error responses should not be affected by congruency. All of these explanations would be challenged if nogo errors occurred more often to incongruent than congruent nogo displays and if speed of error response was affected by congruency.

In the present experiment the proportion of go trials are varied from .50 to .90 and subjects are presented displays comprising a central go or nogo digit which was flanked on both sides by a pair of congruent or incongruent digits. The expectation is that RTs on go trials will be longer to incongruent than congruent displays when go prevalence is low (50%) but that this FCE will diminish to zero or near zero when go prevalence is high (90%). Further, congruency is not expected to affect the probability nogo error or speed of response to nogo digits. Additionally, it is expected from Experiments 1 to 4 that error responses to nogo digits will be faster than responses to go digits.

7.2 Method

Participants

A total of 520 students (349 female) from an introductory psychology class at the University of Canterbury completed the tasks during the first of their regular weekly laboratory sessions. All participants had normal or corrected-to-normal vision. Participants ranged in age between 17 and 66 years (*M* = 19.9 years, *SD* = 4.9 years). The research was approved by the University of Canterbury Human Ethics Committee and students were asked if they wished not to have their data included anonymously in any published study. None elected to withdraw their data.

Apparatus

Participants were tested in groups of 25-36 seated at individual work stations in a larger laboratory at the university. They were seated approximately 50cm in front of an LCD computer screen (377 mm x 303 mm, 1680 x 1050 pixels, 60 Hz refresh rate) that was mounted at eye level. Their head movements were not restrained. Stimuli presentation and response accuracy and timing were achieved using E- prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002). If subjects made multiple responses on a trial these were all were recorded but response time was recorded for the last response alone. Responses were recorded with millisecond precision using the left mouse button connected to a serial port of an i7 PC computer running Windows 7. Mobile phones were deactivated for the duration of the experiment.

Procedure

Each trial consisted of a 5-digit horizontal string displayed in the centre of the screen and comprising a central target digit and four identical flanking digits, which were never the same as the target. The digit strings, visible for 250 ms, were followed by a central “+” fixation for 900 ms; trials were presented at the standard SART rate of one every 1150 ms. Digits were displayed in black in Consolas 60-point font on a white background. Subjects were instructed to press the left mouse button with their right index finger whenever a central digit less than 5 appeared (go digits) and to make no response when anything else appeared. Digit strings were either congruent or incongruent (except for a group presented only single digit displays). Congruent strings were those where flanking and target digits were associated with the same response action (e.g. 44244 = press button, 66866 = withhold). With incongruent strings actions associated with the target and flanker were different (e.g. 44644 - respond and 77377 - withhold). Congruent strings were presented on 80% of trials to all groups to enhance the effect of flanker congruity (Eriksen & Eriksen, 1974; Lehle & Hübner, 2008; Sanders & Lamers, 2002).Subjects were presented 250 trials randomized over 50-trial blocks. Additionally, subjects received 50 practice trials appropriate to their condition with error feedback rather than the typical 18 trial SART procedure. The greater practice provided opportunity for subjects to realize that flanker congruent trials were relatively common so as to facilitate flanker congruency effects.

Table 7.1.

Experimental groups

Group	**Task**	**Stimuli**	**p(go)**
Go-nogo .500	go-nogo	Flanker	0.500
Go-nogo .633	go-nogo	Flanker	0.633
Go-nogo .767	go-nogo	Flanker	0.767
Go-nogo .900	go-nogo	Flanker	0.900
Single digit	go-nogo	single digit	0.900

There were five experimental groups as displayed in Table 7.1. Four groups completed the flanker go/nogo task. These four groups differed in the proportion of go trials they experienced (see Table 7.1). There was also a .90 no-flanker group (to ascertain whether the presence of flankers and the extended nogo digit set produced results comparable with standard SART. Subjects in each laboratory class were randomly assigned to a group.

7.3 Results

While a few subjects made multiple button press responses on many trials (up to 7 responses on some trials) overall multiple responses were infrequent. In an attempt to remove subjects who did not to engage in the task because they either pressed a button repeatedly regardless of stimuli conditions or failed make a response on a majority of go trials, only subjects who made multiple responses on fewer than 20% of go trials and who made a single response to at least 50% of go digits were included in the following analyses. The number excluded from each group ranged from 3 to 7 out of the approximately 100 subjects per group and the number excluded did not appear to be related to the proportion of go trials.

Trials on which remaining subjects made multiple responses were not included in the analyses. The probability of multiple responses ranged from .001 (63% go trials) to .007 (90% go trials).

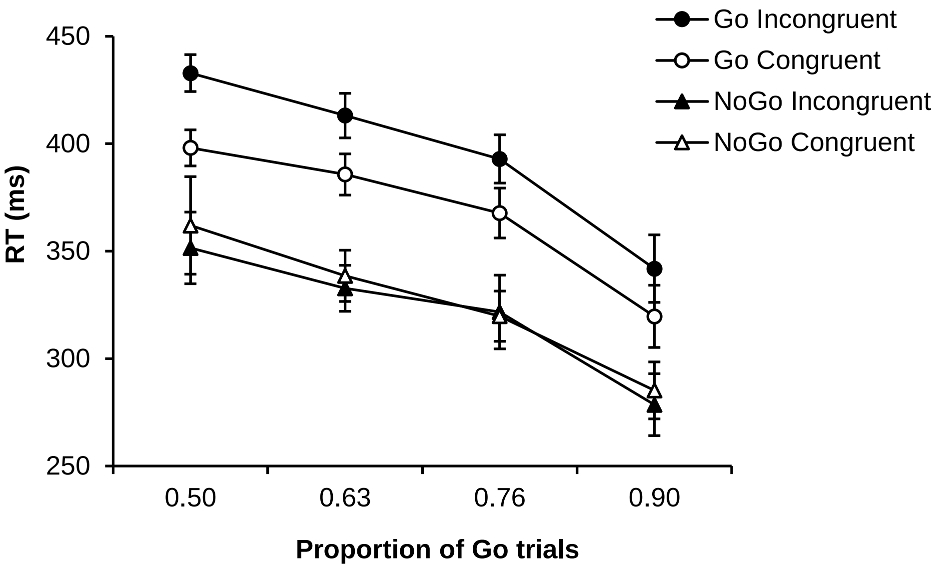


Figure 7.1. Group mean RT for congruent and incongruent displays. Error bars are 95%Confidence Intervals.

The effects of congruency on andgo RTS. For each subject mean go and mean nogo RT was found for congruent and incongruent trials. The means of subject mean RTs are displayed in Figure 7.1. Subject mean RTs were treated by a mixed Prevalence group X go vs. nogo X Congruent vs. Incongruent ANOVA. The congruency X go vs. nogo interaction was significant, $F(1, 368) = 45.7, p < .001, \eta_p^2 = .11$. No other interactions were significant. Averaged over all prevalence groups the mean FCE for go trials was 27.4 ms and 2.7 ms for nogo trials. Separate mixed Prevalence group X Congruency analyses were performed on go and nogo data.

For go data RTs from fell from near 400 ms (50% go) to 320 ms (90% go), $F(3, 407) = 42.3, p < .001, \eta_p^2 = .238$. Both linear (p < .001) and quadratic (p = .004) trend components were significant. Also there was a strong congruency effect, $F(1, 407) = 566.6, p < .001, \eta_p^2 = .582$, and a smaller prevalence X congruency interaction effect, $F(3,407) = 5.7, p = .001, \eta_p^2 = .040$. Mean FCE (incongruent minus congruent RT) was found for each prevalence group. Results were: 50% go $M = 34.8$ ms, 95%CI [30.4, 39.2]; 63% go $M = 27.4$ ms, 95%CI [22.7, 32.1]; 76% go $M = 25.2$, 95%CI [20.6, 30.0]; 90% go $M = 22.2$, 95%CI [17.8, 26.6]. Turning to the analysis of nogo trials, RTs fell by approximately 80 ms from 357 ms (50% go group) to 280 ms (90% go group) with increasing go prevalence, $F(3, 368) = 24.8, p < .001, \eta_p^2 = .168$. However the congruency effect was not significant, $F(1, 368) = 0.4, p = .528, \eta_p^2 = .001$. . The prevalence group X congruency interaction did not approach significance, $F(3, 368) = 0.3, p = .823, \eta_p^2 = .002$.

Overall responses made in error to nogo displays were faster ($M = 322$ ms) than responses to go displays ($M = 378$ ms), $F(1, 368) = 482.9$, p < .001, $\eta_p^2 = .573$, $M_{\text{Difference}} = 56$

ms but as noted above the go vs. nogo X congruency interaction was significant. Examination of Figure 7.1 indicates that the go vs. nogo difference was greater for incongruent (71 ms, 95%CI [63,77]) than congruent displays (40 ms, 95%CI [34, 47]). This difference occurs because congruency has no effect RTs on incongruent trials but incongruent go trials are relatively slower.

The effects of congruency on nogo errors. The probability of nogo error was computed for each subject in the flanker groups separately for congruent and incongruent trials. Group means are displayed in Figure 7.2. Subject nogo error rates were treated by a mixed Groups X Congruency ANOVA. Errors increased as the proportion of go trials increased, $F(3,407) = 156.0$, $p < .001$, $\eta_p^2 = .535$. Only the linear trend component was significant ($p < .001$). Responses to nogo displays were also more common on incongruent ($M = .368$) than congruent trials ($M = .270$), $F(1,407) = 165.5$, $p < .001$, $\eta_p^2 = .283$. The prevalence group x congruency interaction did not approach significance, $F(3, 407) = 0.8$, $p = .505$, $\eta_p^2 = .006$. Notably even when go prevalence was 90% nogo errors were more common with incongruent displays, $t(106) = 4.17$, $p < .001$, $M_{\text{Difference}} = .086$, 95%CI [045, .126].

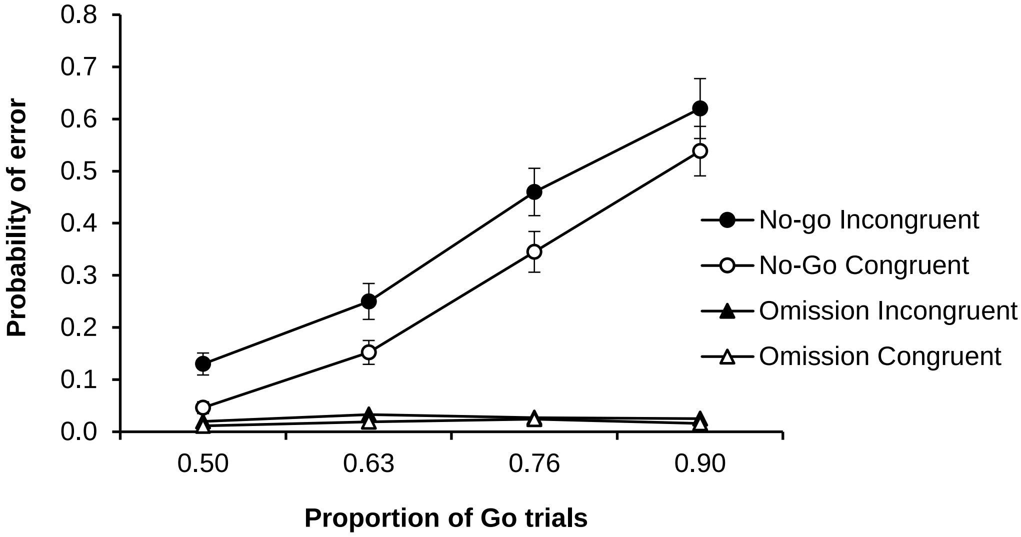


Figure 7.2. Probability of nogo and omission errors for congruent and incongruent displays. Error bars are 95% Confidence Intervals.

Omission Errors. Omissions (failure to make any response to a go display) are also presented in Figure 7.2. A mixed Prevalence group X Congruency ANOVA was performed on subject congruent and incongruent probability of omission. The probability of omission did not differ significantly between prevalence groups, $F(3, 407) = 2.0$, $p = .215$, $\eta_p^2 = .011$ and the interaction of prevalence X congruency did not approach significance, $F(1, 407) = .811$, $p = 488$, $\eta_p^2 = .006$. However omissions were more common on incongruent trials, $F(1,407) = 12.30$, $p < .001$, $\eta_p^2 = .0.029$, $M_{\text{Difference}} = .009$, 95%CI [.004,.013]. In summary omissions overall were rare, they did not increase with proportion of go trials, but they were slightly more common on incongruent go trials when flanking digits indicate a response should be withheld.

Has changing the stimulus set affected performance? The SART typically involves single digit displays with a single nogo digit (usually 3) and a larger but discontinuous set of go digits (1-2 and 4-9). In the current experiment the go vs nogo classification was determined by digit magnitude (less than or greater than 5) and flanking digits were introduced. In attempt to assess any effects of stimulus set and the introduction of flankers on overall task performance, the following groups were compared: the single digit 90% prevalence group, 90% prevalence flanker group and the 90% group from Experiment 4 which had single nogo digit set and single digit displays. Group error rates (pooled over congruency for the flanker group) and go and nogo RTS are presented in Figure 7.3. An independent samples Kruskal Wallis test found no difference in omissions between the groups, $H(2) = .378$, $p = 828$. Similarly an ANOVA performed on subject's nogo errors found no difference in error rates between groups, $F(2, 244) = 1.5$, $p = .215$, $\eta_p^2 = . .013$. Finally a mixed group X go vs. nogo ANOVA was performed on subject mean RTs (pooled over congruency for the flanker group). RTs were longer than nogo RTs, $F(1, 244) = 195.4$, $p < .001$, $\eta_p^2 = .445$ but the groups go vs. nogo interaction effect was not significant, $F(2, 244) = 2.2$, $p = .117$, $\eta_p^2 = .017$. However groups did differ in their overall speed of response, $F(2, 244) = 3.3$, $p = .038$, $\eta_p^2 = .026$. This analysis was followed by a set of simple contrasts comparing no flanker multiple nogo digit set from the current experiment in turn with the flanker group from the current experiment (to isolate the effect of flankers) and the single digit display single digit nogo set from Experiment 4 (to isolate the effects of nogo digit set). The contrast between the two multiple digit set groups was not significant, $p = .900$ suggesting that RTs were not changed by the introduction of flankers. The contrast between the two single digit display groups revealed that RTs were faster in the single digit nogo set condition, $p = .016$, $M_{\text{Difference}} = 28$ ms, 95%CI [5.3, 50.6].

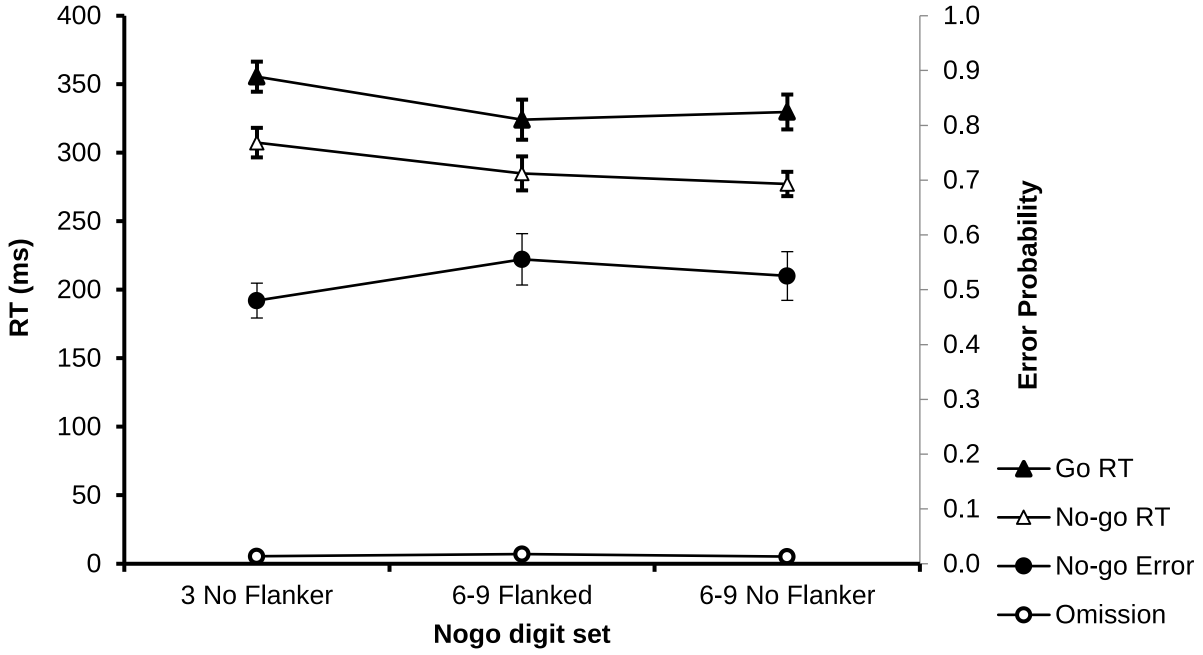


Figure 7.3. Mean RTs and error rates for flanker and single display groups having 90% go trials. Error bars are 95% Confidence Intervals.

7.4 Discussion

The experiment used a modified version of the SART that utilized flankers to test if RTs on go trials would be longer to incongruent than congruent displays when go prevalence is low (50%) and if so to test if this FCE diminishes to zero or near zero when go prevalence is high (90%). Additionally, the expectation is that congruency will not affect the nogo error rate or speed of response to nogo digits regardless of go prevalence. A finding of a RT congruency effect with nogo digits is inconsistent with the view that commission errors occur because of impaired perception or impoverished extraction of digit numerical value from the displays. Finally, it was expected, based on results from chapter 6, that RTs to both go and nogo digits would decrease with increasing prevalence of go trials and that error responses to nogo digits would be faster than responses to go digits. All of these predictions were fulfilled with the exception that nogo errors were more common to incongruent than congruent displays.

Not only did congruency affect the probability of nogo error but also the magnitude of this error congruency effect was found to be independent of the proportion of go trials, although the effect of proportion of go trials on error rate was strong. This suggests that the response action indicated by flanker digits is just as likely to be extracted when response and withhold actions are equally likely as when a response is required for 90% of trials. It seems likely that flanker information and its associated response action is extracted automatically without involvement of attention. However, a difference in probability of error due to congruency of just .10 is not large. This difference is independent of the proportion of go trials implying that the extraction of flanker information occurred to a similar extent regardless of the proportion of go trials. If information is extracted to the same degree regardless of the proportion of go trials, why are commission errors more common the greater the proportion of go trials? Perhaps the displays are processed equivalently regardless of the proportion of go trials, but the incidence of errors is greater when go trials are more common because of inability to control the production of a particular action (press a mouse button) not because of poverty of perception. The ability to control the action depends on its level of preparedness (previous chapter) or its utility (Peebles and Bothell, 2004) both of which increase with the proportion of go trials.

Congruency affects the rate of nogo errors and go RTs, but it has no effect on nogo RTs. How is this to be explained? One possibility is that abrupt visual change initiates a button press response process or motor program and this continues until production of an overt button press response unless a stop signal occurs in time to halt it before the button is physically pressed. The fact that commission errors are more common to incongruent nogo displays than congruent displays suggests that the response classification (respond vs. withhold) of flanking and target digits is extracted from nogo displays. However, because the conflicting information in incongruent displays delays resolution of the appropriate respond or withhold action the stop instruction is not delivered in time to halt the fast response process. The consequence of conflicting information is delay in establishing stimulus classification and hence error responses occur more often to incongruent than congruent nogo displays. But RT to a nogo digit will not be affected by congruency because all commission errors are the result of an unstopped fast processes; congruent and incongruent displays will have equally fast responses.

According to Peebles and Bothell (2004) subjects choose between competing encode and click and encode and check strategies on each trial on the SART. Under encode and click a fast response is made as soon as a stimulus is detected. This may be elaborated to mean that upon detection of a stimulus the mouse button click response motor program is initiated. Many studies that show a strategic influence on the FCE (Corballis & Gratton, 2003; Wendt et al., 2008) suggest that subjects apply selection strategies using the utility principle; processing is optimized by allocating a specific amount of attention to the flankers depending on their utility). Attending to the flankers is useful for performance if they are activating the same response, but detrimental otherwise (Lehle & Hübner, 2008). With flanked displays the onset of a stimulus is heralded by a change of display from a small central “+” to a string of five digits whereas with single digit displays the onset of a stimulus is indicated by a change of the “+” (or commonly with the SART from an encircled “X”) to a single digit. With the encode and check strategy subjects delay initiating a response for the duration they estimate is needed to support accurate responding. The likelihood of a strategy being applied changes dynamically from trial to trial depending on the prior history of success of the strategy. Following incorrect application of encode and click, subjects may make an explicit choice to adopt encode and check, or they may simply wait for the next trial effectively ignoring the most recent failure.

Many of the results from this experiment can be accommodated by this model. The long run success of the fast encode and click will be greater the higher the proportion of go trials because there will be fewer occasions when it produces an incorrect outcome (response to a nogo digit). Consequently, RTs to go stimuli will decrease and the nogo error rate will increase with increasing go probability, as was found.

Subjects have no ability in advance of a trial to predict whether the upcoming trial will be a go or a nogo trial because the trial sequence was random. Therefore, the nogo error rate provides an estimate of the proportion responses on go trials that result from application of the fast encode and click strategy. Some proportion of responses to go stimuli will be fast and not involve extraction of information about flanker and target identity. responses generated by encode and click should be incapable of producing any flanker congruency effect. The upshot of this is that as the proportion of go stimuli increases go responses generated by encode and click increasingly displace responses generated by encode and check so that the proportion of trials capable of producing flanker congruency declines with increasing go probability. Consequently, the RT congruency effect on go trials will reduce with increasing go probability. In theory a RT FCE should be detectable even when go probability is high because nogo errors typically fall well short of 100% leaving sufficient encode and check trials to produce a congruency effect. This is consistent with the results from the current experiment where the go RT congruency effect reduced with increasing go probability but remained above zero even when 9 out of 10 trials were go trials.

Thus far falling go RTs, diminished incongruent-congruent RT differences and increased rates of nogo errors with increasing proportion of go stimuli can be accommodated by the Peebles and Bothell model. However other results appear to challenge it.

A major problem for the Peebles and Bothell account is the existence of flanker congruency effects in responses to nogo stimuli. If nogo errors occur because a button press response has been initiated upon detection of stimulus onset, as opposed to digit response class (press a button or withhold response), then there should be no evidence of flanker congruency effects on trials when a nogo error has occurred. To the contrary, nogo errors were more likely to incongruent than congruent displays at all levels of go prevalence. These results suggest that when nogo errors occur flanker response classification is extracted before the inappropriate button press response to a no go display is initiated and that this occurs less often the higher the go probability.

Further if nogo errors occur when detection of stimulus onset results in the inappropriate initiation of a response it is difficult to understand why nogo RTs decrease with increasing go probability because the information signalling response onset is the same (change from “+” to five digits) across all levels of go probability. While congruency had no effect on nogo RTs, as noted, nogo RTs did fall with increasing go probability in a manner very similar to RTs to go stimuli.

The foregoing suggests that rather than being determined by stimulus detection information alone, response initiation on nogo trials is influenced by conflict between target and flanker but the contribution of this conflict to the incidence of nogo errors falls with increasing go probability. These challenges to the Peebles and Bothell model may be accommodated if modifications are made to it. The simplest is to suppose that the mean duration allowed from the detection of stimulus onset to the initiation of a button press response itself reduces with increasing go probability, while varying within some limits from trial to trial. To this is added the supposition that stimulus onset is detected at shorter durations than flanker digit classification and that flanker classification is extracted faster than target digit classification (due to the fact that flanker processing was encouraged by the high proportion of congruent trials and that displays contained one target and four flankers). It follows that if the mean duration available for stimulus extraction falls with increasing go probability then progressively the duration available will become insufficient for target and flanker digit identification resulting in faster RTs to nogo stimuli with increasing go probability and diminishing flanker effect with increasing go probability because at shortest delays even flanker information is not extracted. This explanation is also able to accommodate findings from the experiment reported in the previous chapter, where go probability was varied but with single digit displays.

Chapter – 8

The effects of spatial separation of go and nogo stimuli

Experiment -6

8.1 Introduction

To account for the findings reported in the previous experiments it has been proposed that nogo errors occur when a highly prepared motor program is triggered upon, or soon after, detection of abrupt change in the field of view and that this program runs to completion unless concurrently occurring stimulus processes classify the stimulus as nogo early enough to stop the motor program before overt an response is produced. By this view commission errors should decrease when extraction of stimulus information is fast relative to the response execution processes – stimulus identity will occur before the motor program stop expiry time is reached (Aron, 2011). In chapters 2-5 delaying response production relative to stimulus processing led to a reduction in commission errors. In the current experiments speed of stimulus classification is enhanced and is expected also to reduce commission errors. In the original SART the division of digits into go and nogo categories was arbitrary, with many assigned to the go category. Under these circumstances full identification and classification of stimuli is likely to be relatively slow compared to obvious dichotomies based on difference in location, colour, or shape. For example, if green and red are quickly identified as go and nogo (capitalizing on previously established associations) then commission errors should be few relative to traditional SART as Smallwood (2013) found. Similarly, if shapes such as circle and triangle, or any forms that capitalize on the contrasts that are thought integral to object recognition (Biederman, 1987), are used to designate go and nogo, commission errors should be fewer than in the traditional SART.

In the current experiment go and nogo stimuli occurred in different locations. When all go digits occur in one location and all nogo digits occur elsewhere subjects can use location rather than digit magnitude to determine whether to respond or make no response. In this situation, although instructed to respond to all digits except the digit 3, subjects could completely ignore digit value and still achieve fast RTs with perfect accuracy. The experiment involved three conditions. A traditional SART in which both go and nogo digits appeared in the screen centre (Central go, Central nogo or **CC** condition) was compared with conditions where go and nogo stimuli were spatially separated. In a **CP** condition all go stimuli appeared in the centre of the screen and nogo stimuli appeared equally often to the left and to the right of centre (Central go, Peripheral nogo, hence CP). Finally, the spatial arrangements were reversed in a **PC** condition: go stimuli were presented equally often in the two peripheral locations and all no go stimuli appeared in the centre of the screen. In all three conditions the proportion of go trials was .89. The response requirements are identical in all three conditions so that manipulation of the relative speed of response and stimulus identification processes was achieved by reducing stimulus categorization time alone.

If information regarding location is extracted faster in the CP and PC conditions than digit category in the CC condition nogo errors should be fewer in the CP and PC conditions than CC condition. Furthermore, if stimulus identity is extracted faster when go and nogo digits are spatially separated it is likely that responses to go stimuli will also be faster in the CP and PC conditions. The combination of faster responding with fewer errors is counter to claims that commission errors in the SART are manifestations of speed-accuracy trade-off (Head & Helton, 2014b, 2014a; Helton, Head, & Russell, 2011; Wilson, Russell, & Helton, 2015). An appealing feature of the proposal of a race between response production and stimulus classification is that it can also account for situations where go responses are fast and nogo errors relatively uncommon. The critical factor determining the frequency of nogo errors is not held to be speed of response per se but speed of response relative to speed of classification of a stimulus as nogo. When response processes are fast relative to processes that classify the stimulus as nogo commission errors will be more common.

Subjects also have the ability to prioritize the extent and locus of their field of visual attention (Posner, 1978: Cave & Chen, 2016). In the CC condition all stimuli occur in the one central location so that the field of visual attention is likely to be small and centrally focused at the time stimuli are presented. Similarly, in the CP condition the field of visual attention is likely, at the time of stimulus presentation, to have been confined to a relatively small central region because nearly 90% of stimuli and all stimuli requiring overt response occur centrally. An important difference between the CC and CP conditions is that in the CC condition all go and all nogo stimuli occur within the field of attention whereas in the CP condition, it is expected that all nogo stimuli will occur outside of the attended region. This difference is important because if subjects in high go situations initiate a highly prepared response only to stimuli appearing at an attended location when abrupt visual change occurs inappropriate responding to nogo stimuli should be virtually non-existent in the CP condition.

Defining the extent of the field of visual attention and its locus is more difficult in the PC condition. Here close to 45% of stimuli and 50% of all go stimuli occur randomly in each the two peripheral locations while a little over 10% of stimuli occur centrally. Consequently, the focus of attention may not be confined to a single or small region on most trials. If nogo error rates are similar between the nogo central (PC) and nogo peripheral conditions (CP), then it is likely that subjects are responding to sudden stimulus onset regardless of where the visual change occurs, a finding that has relevance to friendly fire and hunting accident situations.

Connor, Egeth, & Yantis, (2004, p.850) argue that visual attention is drawn to salient stimuli that ‘pop out’ from their surroundings and that attention can be voluntarily directed to “objects of current importance to the observer”. Connor et al., (2004) also suggest that when a cue appears at an identical location to an upcoming target, attention will be focused to the target location in advance causing quicker responses. Because of the possibility that the mask in the SART might act as like a pre-cue and direct attention to its location no mask followed stimuli in the current experiment.

8.2 Method

Participants

Sixty undergraduate students (31 female) from an introductory psychology class at the University of Canterbury participated in exchange for course credit. All participants had normal or corrected-to-normal vision. Participants ranged in age between 17 and 49 years (M = 21.2 years, SD = 5.4 years). The research was approved by the University of Canterbury Human Ethics Committee and students were asked if they wished not to have their data included anonymously in any published study. None elected to withdraw their data.

Apparatus

Participants were tested in groups of 10 seated at individual cubicles in a larger 35-cubicle psychology laboratory at the university. They were seated approximately 50cm in front of an LCD computer screen (377 mm x 303 mm, 1680 x 1050 pixels, 60 Hz refresh rate) that was mounted at eye level. Their head movements were not restrained. Stimuli presentation and response accuracy and timing were achieved using E- prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002). All responses occurring in the 1150 ms interval between stimulus onsets were recorded but on trials where more than one response was detected, response time for only the last response was recorded. Response times were recorded with millisecond precision using the left mouse button of a mouse connected to a serial port of an i7 PC computer running Windows 7. Mobile phones were deactivated for the duration of the experiment.

Stimuli and procedure

Stimuli were the numerals 1–9 displayed in black Symbol 94 pt font on a white background for 250ms. Stimuli were replaced by a blank white screen for 900 ms until followed by display of the digit for the next trial. The digits were presented equally often but randomized over the entire set of 225 trials. The digit 3 was the designated nogo and the remaining digits were go digits. Responses made within 1150 ms of a digit onset were accepted and participants were asked to press the left mouse button as quickly as possible to digits while avoiding making any overt response to the nogo digit. As is standard with the SART subjects completed 18 practice trials, which gave accuracy feedback, before commencing the main experimental trials. The entire experiment took about 10 minutes to complete. Participants were randomly assigned on arrival for testing in a between groups design to either the CC, CP or PC condition.

8.3 Results

A total of 21 subjects (between 6 and 8 per group) registered more than a single mouse button press response on at least one trial. The number of multiple responses per subject ranged from 1 to 5. Where these occurred on nogo trials they were counted as commission errors. Trials involving multiple responses were excluded from the analysis of RTs because on these trials the time for the last response alone was recorded.

Omission Errors: Omissions were rare. Median omission errors rates were 0.000 for the CC group, and .005 for both the CP and PC groups. No significant difference between groups in omissions was detected; Kruskal-Wallis independent samples test $H(2) = 2.30$, $p = .36$.

Commission Errors: Group mean commission errors are displayed in Figure 8.1. Subject probability of commission errors were treated by a between groups ANOVA. Group means differed, $F(2,57) = 27.71$, $p < .001$ $\eta_p^2 = .493$. Follow up Bonferroni tests revealed that commission errors were more common in the CC ($M = .470$) than CP ($M = .138$) condition, $p < .001$, $M_{\text{Difference}} = .332$, 95%CI [.22, .44] and marginally more common than in the PC ($M = .358$) than CC condition, $p = .050$, $M_{\text{Difference}} = .112$, 95%CI [.000, .224]. Commission errors were also more frequent in the PC than CP condition, $p < .001$, $M_{\text{Difference}} = .220$, 95%CI [.108, .332]. Further, one sample *t*-tests performed separately for the CP and PC data revealed that commission errors were not eliminated when go and no go stimuli were spatially separated: for the CP condition $t(19) = 6.02$, $p < .001$, $M = .138$, 95%CI [.09, .19]; PC condition $t(19) = 8.89$, $p < .001$, $M = .358$, 95%CI [.274, .442].

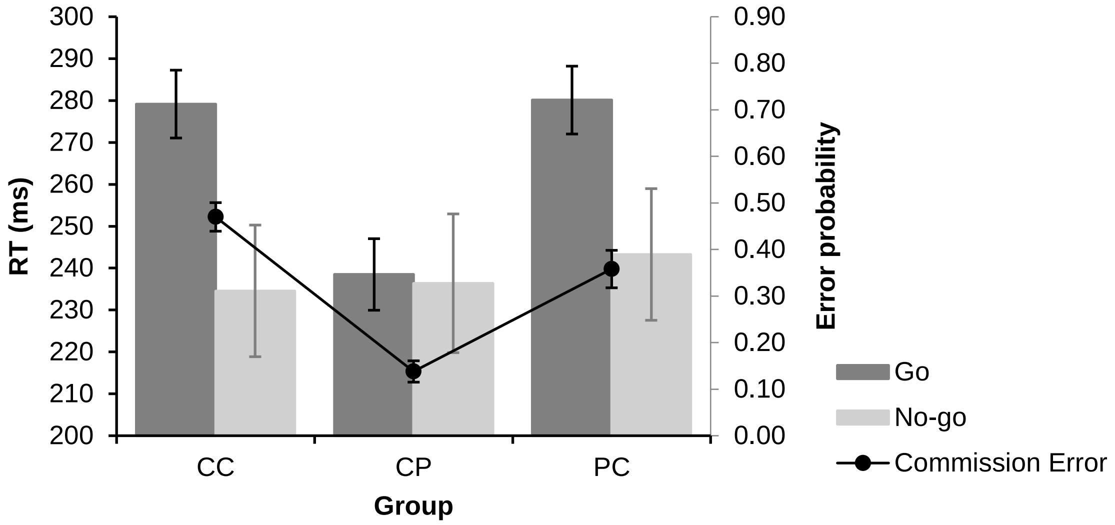


Figure 8.1. Group mean RTs and mean probability of commission error. Error bars are standard error of the mean.

Response Times: Group mean go and nogo RTs are displayed in Figure 8.1. Subject mean go and nogo RTs were treated by a separate between groups ANOVAs because group go and nogo SDs were quite different, especially for the CP group. Mean go RTs differed, $F(2,57) = 6.44$, $p = .003$, $\eta_p^2 = .184$. Bonferroni tests revealed that compared to the CC condition separating the locations of go and nogo RTs speeded go responses in the CP condition, $p = .010$, $M_{\text{Difference}} = 35.9$ ms, 95%CI [7.0, 64.7] but not in the PC condition when go stimuli appeared in different off-centre positions, $p = 1.000$, $M_{\text{Difference}} = - 1.0$ ms, 95%CI [-29.8, 27.9]. Responses were faster in the CP than PC condition, $p = .008$, $M_{\text{Difference}} = -36.8$ ms, 95%CI [-65.7, -8.0]. Turning to responses made in error to nogo stimuli a between groups ANOVA revealed there was no detectable difference between groups in their mean nogo RTs, $F(2, 55) = .08$, $p = .919$, $\eta_p^2 = .003$. Finally the difference between go and nogo RTs was explored for each group using related measures *t*-tests. For the CC and PC groups responses to nogo digits were faster:,CC. group $t(19) = 8.18$, $p < .001$, $M_{\text{Difference}} = 44.6$ ms, 95%CI [33.2, 56.0]; PC group, $t(19) = 6.93$, $p < .001$, $M_{\text{Difference}} = 36.8$ ms, 95%CI [25.7, 48.0]. There was no detectable difference between go and nogo RTs for the CP group, *t*(17) = .08, *p* = .938, $M_{\text{Difference}}$ = 2.1 ms, 95%CI [-54.1, 58.4]. Two subjects in the CP group made no commission errors and hence no RTs.

8.4 Discussion

This experiment attempted to test three primary hypotheses: 1) If stimulus classification is faster in the CP and PC conditions than CC (due to spatial separation) then fewer commission errors should occur in these conditions along with faster go RTs. 2) If responses are initiated only to attended locations we should theoretically expect no commission errors in the CP condition. 3) If commissions in CP and PC conditions are the same then subjects may not be responding to sudden onset.

In go/nogo tasks such as the SART go and nogo stimuli are typically presented in a single central location so that perfect classification of stimuli as go vs. nogo necessarily involves identification the digits. However, when go and nogo stimuli always appear in different locations digit value becomes irrelevant and perfect classification of stimuli as go vs. nogo can be made on the basis of location alone. If nogo errors occur in high go tasks because response production processes outrun concurrent stimulus identification processes, then the rate of nogo errors should be reduced by any manipulation that speeds stimulus classification relative to response production. In experiments 1 to 3 (chapters 2 to 5) stimulus categorization was speeded relative to response production by delaying response production. In the current experiment it was hoped that spatial separation of go from nogo digits would again advantage stimulus categorization relative to response production, this time because determination of location should take less time than categorization of digits. Consistent with this expectation the probability of nogo error fell from nearly .50 to near .15 when all go stimuli were centrally located and nogo stimuli occurred in two off-centre positions At the same time, speed of response to go stimuli fell by around 36 ms to be equal to the normally faster error responses. Notably this result is not an example of speed-accuracy trade-off which has previously been put forward as an explanation for nogo errors (Head & Helton, 2014b, 2014a; Helton, Head, & Russell, 2011; Wilson et al., 2015).

However, when locations were reversed so that all nogo digits appeared centrally while go digits were randomly dispersed between two off-centre locations the drop in error was much less, close to .35 although go RTs were almost identical to those in the traditional situation where all stimuli appear centrally. The fact that the different spatial arrangements result in different rates of commission error and differing response speeds might be taken to suggest that when go and nogo digits appear in different locations subjects do not initiate their response immediately upon detection of abrupt change in their field of view.

When all go stimuli and only go stimuli occur in the centre in a high go task the area encompassed by the field of attention is likely to be small and have its locus precisely where the digits occur, and importantly, be focussed at the location prior to stimulus presentation. By contrast when go stimuli are dispersed between two peripheral locations and much rarer nogo stimuli occur in the centre, more options are possible. The field of attention may comprise a single continuous area incorporating both off-centre locations and the centre. This situation is similar to the traditional SART in that both go and nogo stimuli occur within the focus of attention but now within a much larger field. Alternatively, subjects may confine their field of attention to one or other of the off-centre locations on each trial depending upon their expectations regarding the location of the next go trial and they may even focus attention in the centre if they believe a nogo trial to be imminent. Regardless subjects are often likely to locate attention in the wrong place on around half of all trials. If the locus of attention is in the wrong place sudden onset of the stimulus in a non-attended and empty location will bring about a shift of attention to the location of the stimulus (Posner, 1978: Cave & Chen, 2016). In both of these scenarios stimulus classification is likely to be retarded relative to the situation where all go stimuli appear centrally. As a result, commission errors are expected to be greater and RTs longer when go stimuli appear in two rather than a single location. However, when stimuli are not central, but the positions are readily discriminable, there is no link between peripheral locations and response, so generally they don't respond to peripheral events, unless occasionally sudden onset over-rides everything.

Spatial separation alone does not appear to be the sole driver of differences in RT and Commission errors. Turatto & Galfano, (2000) have shown that attentional capture can be triggered by manipulations of colour, form, and luminance suggesting that these physical properties can capture attention automatically. Relative to the traditional situation where go and nogo stimuli are both centrally located the combination of shorter RTs and fewer commission errors occurred only in the CP condition. What difference between the CP and PC conditions could account for the combination of greater speed with fewer errors in the CP condition? In the CP condition stimuli always occur in one location (centre), whereas in the PC condition stimuli occur equally often on the left and the right. In the CP condition subjects can be certain about the location of a go stimulus and direct the focus of attention accordingly. However, it is not possible to similarly determine a suitable locus for attention on every trial in the PC condition. A possibility is that participants adopt a narrow attentional zoom to exclude the peripheral distractors making it easier to ignore the nogo stimuli. It could be that the inferior performance in the PC condition relative to the CP occurs because the "beam" is cast too wide and the central stimuli cannot be ignored if they are monitoring both peripheral positions. If there is a quick and early process that reliably distinguishes go from nogo digits subjects will adopt it after a few initial trials as may have happened in Smallwood (2013) when all nogo stimuli were red and all go black. The inclusion of black nogo and red go requires a more detailed analysis of digit identity, and the more lengthy discrimination process prevents responses initiated by sudden onset to be halted before a response is produced, leading to a higher incidence of commission errors.

Both the CP and PC conditions involve the addition of peripheral locations and it could be argued they should result in similar reductions in nogo errors. However, on closer inspection it may not be correct to assume that the CP and PC conditions involve equal variety simply because they both involve three locations. Variety or uncertainty is quantifiable by using a measure derived from information theory (Fitts and Posner, 1967 pp. 85-87). Uncertainty or variety is quantified in terms of the H, in which a situation involving two equally likely but unpredictable alternatives has $H = 1$ bit of uncertainty. For the CP condition $H = .55$ and for the PC condition $H = 1.39$. This is because in the PC condition the variation in location involves the more frequent category (go) whereas in the CP condition variation in location involves the rarer nogo category. By the uncertainty metric, the PC condition is more varied and therefore should provide more exogenous support for attention and in turn lead to fewer commission errors than are expected in the CP condition.

Response requirements are the same in all three conditions. If it is repetitive responding alone that results in impoverished support for the maintenance of attention to the task (Robertson et al., 1997 etc.), then there should be no difference in commission errors between the three conditions in this experiment (which was not the case). Helton and colleagues take a different view (Helton et al., 2005, 2009). They argue that the additional task-induced cognitive load introduced by spatial uncertainty interferes with performance (Fitts & Posner,1967) and therefore should increase nogo errors. Based on these arguments our results would bode poorly for the perceptual decoupling argument as its appears that spatial uncertainty has not enhanced performance on the task in the PC condition when compared to the CP condition, in fact the result is the reverse of prediction. Perhaps future experiments could involve placing the centre and off-centre locations on the surface of a single object and comparing it with locations on the surfaces of two distinct objects. The expectation would be that commission errors will be far fewer when the locations of go and nogo stimuli are perceived to be on separate object surfaces.

Chapter 9

General Discussion

Go/nogo tasks are currently used for at least two major purposes: to measure sustained attention among a wide variety of clinical populations (see Seli 2016 and Chapter 1 for reviews), and, especially in neuroscience, as a measure of response inhibition (for reviews see Aharoni et al., (2013); Criaud & Boulinguez, 2013). That similar go/nogo tasks are used to measure apparently different constructs suggests some general lack of understanding at a theoretical level of the cognitive processes and mechanisms underlying performance on go/nogo tasks. The experiments reported in this thesis were motivated by disagreement among explanations of performance on the Sustained Attention to Response task (SART) (Robertson et al., 1997), but can be considered in a broader context.

In the SART subjects are instructed to respond by pressing a button or key as quickly as possible to the digits 1-9 but to make no response to a designated nogo digit (typically 3). Robertson et al. (1997), who developed the task, proposed that inappropriate response to the nogo digit (nogo error or commission error) occurred during moments when attention to responses had lapsed allowing the triggering of an automatized button or key press response, which was appropriate on 89% of trials. Helton and colleagues (Finkbeiner et al., 2015; Head & Helton, 2013, 2014b; Helton, Head, & Russell, 2011; Helton et al., 2009) provide data and argument which can be interpreted as broadly in agreement with the proposal that errors result from problems controlling or inhibiting a pre-potent motor response, a view that has similarities to the notion of inhibitory control, which is assumed in many neuro-imaging studies.

More recently attention lapse has been conceived as a product of mind-wandering, which in turn leads to a state where attention is said to be decoupled or disconnected from perception (Schooler et al., 2011; Smallwood & Schooler, 2015) An important difference between this explanation of nogo errors and Robertson et al. (1997) is that Robertson et al. consider the lapse in attention to affect response control, while the term “perceptual decoupling” implies that errors occur because of failure on the part of perceptual processes to correctly classify stimuli as go vs. nogo, or perhaps because of failure to select the go vs. nogo classification of the digit as the determinant of whether a response should be made or withheld.

Agreement that attention has a role to play in the genesis of nogo errors in the SART is not universal. Peebles and Bothell (2004) explicitly deny any role for attention. Instead they propose that errors occur when people choose to act speedily without consideration of results of analysis of sensory information (their encode and click strategy) rather than elect to respond only after information extraction has led to classification of the current digit as go, or not nogo (encode and check strategy). The two strategies are in competition on each trial. Which process wins is determined by the relative benefits of speed against cost of error, which is determined historically from previous success (of correct response and correct withhold) and error (respond to a nogo digit, and more rarely omission). The big contribution of the Peebles and Bothell model is the introduction of the idea that the probability of committing nogo errors can be conceived in terms of costs and benefits of respond and withhold actions. The experiments reported in this thesis were conceived against this background. An initial aim was to establish the relative roles of perceptual analysis, motor control, and the selective processes of attention on SART performance.

Typically, SART stimuli are displayed for 250 ms. As shown in chapters 2 to 5 digits can be reliably identified when displayed for just 50 ms. This leaves opportunity for re-engagement of attention should a subject have been perceptually decoupled when the digit first appeared. The opportunity for re-engagement of attention with perception should be severely reduced when display duration is a mere 50 ms, provided it is followed by a mask that effectively terminates the display (Kouider & Dehaene, 2007). Consequently, if nogo errors occur when attention is decoupled from perception it is expected that the errors will be more prevalent with briefer than longer displays. To the contrary, it was found in each of the experiments in chapters 2, 3 and 4 that reducing the duration of stimuli to 70 ms and then 50 ms had no detectable effect on nogo errors or go and nogo RTs. The conclusion drawn from the results of these close replications of SART procedures was that either re-coupling of attention with perception did not occur during the lifetime of a 250 ms display or perceptual decoupling did not occur at all in these experiments.

Another way to assess the role of perceptual decoupling is to have subjects delay the production of their responses to briefly presented stimuli. When stimuli are presented briefly and followed immediately by a mask that effectively terminates the display, requiring subjects to delay production of their responses should provide no additional opportunity to benefit from perceptual processing of stimuli and therefore introducing delay should have no effect on the probability of nogo error. To the contrary nogo errors fell in all three experiments where subjects were instructed to delay responses for 250 ms or more. These results concur with others who delayed response production by extending the motor requirements of responding (Head et al., 2017; Wilson et al., 2018) or by requiring subjects to synchronize their response production to a regular tone (Seli, Cheyne, Barton, & Smilek, 2012). In some conditions in these studies nogo errors were reduced to as low as 2% and 5%. If it is accepted that recovery from perceptual decoupling is unlikely with the longer displays used in these studies (based on the finding that reducing stimulus variation had no detectable effects nogo errors in experiments 1,3 and 3), then delaying responses may reduce nogo errors in SART-like tasks to near zero levels and leave little or no room for perceptual decoupling or any explanation of nogo errors that has stimulus processing or lack of correct classification of stimuli as the cause of error.

Nevertheless, response delay had a less dramatic effect in the present experiments; nogo errors exceeded 20%. One reason for the lesser effect of delay interval in the current experiments may be the nature of the delay task itself. While Seli et al (2012) report greater reduction in nogo error with increasing delay interval using a metronome synchronization task, no difference in nogo errors occurred in Experiment 2 across delay intervals from 250 to 650 ms. The lack of additional reduction in nogo errors at longer delay intervals may reflect the fact that on occasions subjects in Experiment 2 went on to respond when the mask changed although they had successfully resisted responding to the nogo digit on the same trial.

One question that has been overlooked so far is what actually triggers a response to a nogo stimulus in the SART and similar tasks. Robertson et al. (1997) ascribe response production on nogo trials to execution of an automatized button press response. But what triggers the automatized action? Peebles and Bothell (2004) propose that high benefit of speed and rare cost from error causes adoption of a fast strategy in which response production is initiated before the stimulus has been classified. Again, if the response is not triggered by stimulus classification what triggers the fast response? The finding in Experiment 2 that subjects who had made no response to a digit but later in the trial responded quickly following the mask change suggests that abrupt visual change may be the trigger that initiates rapid response to nogo stimuli in high-go tasks like the SART. This is consistent with the finding that responses to nogo stimuli were 50 ms to 70 ms faster than responses to go stimuli in all no-delay conditions in the experiments reported in this thesis except in Experiment 6 (chapter 8) when go and nogo stimuli appeared in different locations.

One factor likely to increase the propensity to respond to nogo digits is level of preparedness (Miller 1998) of the button or key press response. Probably the strongest influence on preparedness or expectation that a response is required on a particular trial is the proportion or prevalence of go trials experienced. The idea that response preparedness and expectation increases propensity for nogo error is built into the original explanation of nogo errors proposed by Robertson et al. (1997) According to Robertson et al. more frequent repetitive responding to go stimuli leads to increased automatization of the response and also increases the likelihood of attention lapse. The same prediction can be derived from mind-wandering perspectives if it is assumed that mind-wandering, and hence the decoupling of perception from perception, is more likely the more repetitive and less intrinsically variable the task environment. Peebles and Bothell (2004) suppose that adoption of the fast encode and click strategy depends on the extent to which the benefits of speed outweigh the cost of error. The higher the prevalence of go trials the more likely a fast encode and click response will incur nogo errors. All theories predict increasing probability of nogo error with increasing proportion of go trials. While others have explored the effects of go prevalence across a narrow range of go prevalence using the SART (Manly et al., 2000) or across a wider range of go proportions in a SART-like task (Wilson et al., 2018) there appears to be no published study exploring the effects of go prevalence on SART performance at several levels from low (50%) to high (98%) prevalence. Experiment 4 was designed to fill that gap.

Preparedness of a response may also affect its latency and/or speed of execution. Robertson et al. proposed that speed of response would increase the longer the uninterrupted run of go trials. Because average run length increases with increasing proportion of go trials RTs to both go and nogo stimuli should decrease with increasing go prevalence. More precise predictions can be derived from Peebles and Bothell (2004). Because their model predicts that fast encode and click responses become more frequent with increasing go prevalence it follows that the mix of fast click and slower encode and check strategies will shift in favour of fast click as go prevalence rises, and hence go RTs are predicted to decrease with increasing go prevalence. However, since nogo errors result from application of the same fast click strategy error responses to nogo stimuli should remain constant across all levels of go prevalence. Similarly, if response production on nogo trials is triggered by detection of abrupt visual change that occurs with stimulus onset then speed of response to nogo stimuli should remain much the same regardless proportion of go trials. Importantly the differing predictions for the effects of go prevalence on speed of response to nogo stimuli provides a test which seems capable of discriminating the attention based theory of Robertson et al from the Peebles and Bothell model that includes no role for attention and the proposal that nogo errors arise when subjects respond to abrupt visual change, regardless of its source.

Experiment 4 (chapter 6) was a very close replication of SART procedures, the only change being the proportion of go trials. prevalence was also varied in Experiment 5, this time in fewer and larger increments from 50% go to 90% go and where go and nogo digits were flanked on either side by congruent or incongruent distractor digits. Despite these and other differences the probability of nogo error increased with go prevalence and at similar rates between the two experiments. At the same time RTs to go stimuli decreased in both experiments and more steeply when go prevalence exceeded about 76%. Of particular interest is the relationship between go prevalence and RTs to nogo stimuli. In both experiments speed of response to nogo digits also decreased with the prevalence of go trials and at a similar rate to go stimuli. Also RTs to nogo stimuli were about 50 ms to 60 ms faster than responses to go stimuli.

The finding that responses to nogo digits became faster the greater the proportion of go trials poses difficulties for any theory which assumes nogo errors are generated by a single process that has a constant completion time regardless of proportion of go trials. These results suggest that the fast click strategy of Peebles and Bothell (2004) and the proposal put forward above that nogo errors occur when response is triggered by detection of abrupt change in the visual field are not viable in their present forms. They could remain viable if it were supposed that speed of execution of the encode and click process and detection of abrupt change themselves increased with go prevalence. When go prevalence is high preparedness and expectation of response is higher and it is possible that the act of responding is delivered more confidently with force (the key is pressed harder) and as a result more quickly or perhaps the response is initiated sooner due to of a lower threshold for the detection of visual change in high go situations. However, these alone may not be sufficient to account for the 70-80 ms drop in nogo RTs. Another possibility stems from visual search studies. Here it has been found that when the proportion of target absent trials is high subjects terminate the search process earlier (Rich et al., 2008). The analogous situation in go/nogo is that when the proportion of go trials is high and making a response has low cost subjects will terminate stimulus information extraction processes early and not delay response production long enough to establish the stimulus as go or not nogo.

The main purpose of Experiment 5, which involved congruent and incongruent flanking digits (Eriksen & Eriksen, 1974; Lehle & Hübner, 2008; Sanders & Lamers, 2002), was not to explore the effects of go prevalence but to use go prevalence in combination with the congruency relation between a central target digit and so-called distractor flanking digits to explore the extent of information processed from displays in high go tasks. Normally the flanker congruency effect (FCE) is evidenced by the difference in RT between incongruent minus congruent displays in 2-choice tasks. In the present context a FCE for go trials is defined as the RT difference between incongruent minus congruent displays.

Since both Roberston et al. (1997) and perceptual decoupling explanations (Schooler et al., 2011; Smallwood & Schooler, 2015) suppose that attention is engaged on a majority go trials, they predict a positive FCE for go trials. Similarly, Peebles and Bothell (2004) predict a positive FCE for go trials because generally responses result from application of the slower encode and check strategy, which it is expected will lead to classification of both central and flanking digits. Results from Experiment 5 provide clear evidence of a FCE congruency effect on RTs in go trials.

More interesting are nogo trials. A subject who is perceptually decoupled during presentation of a display should not have access to the results of perceptual processing of the display and therefore no FCE effect is expected on nogo trials. According to Peebles and Bothell (2004) nogo errors occur when people adopt the fast encode and click strategy initiating a response without regard to stimulus classification. Again no FCE is expected on nogo trials. Similarly, if error responses on nogo trials occur because responses are initiated upon detection of abrupt visual change no FCE is predicted on nogo trials. In accord with these predictions no FCE was observed for RTs on nogo trials.

The effects of congruency can also be measured from examination of accuracy or error rates. For go trials an accuracy FCE exists if the probability of omission error is greater on incongruent trials where the central digit is a go digit and the flanking digits are nogo. Although omissions were rare, they were overall slightly more common on incongruent than congruent trials but not affected by the proportion of go trials.-go errors being more common allow greater use of accuracy. An accuracy FCE exists when the probability of response to a nogo display is higher for incongruent than congruent displays. The probability of nogo error was a little under 0.1 higher when the central digit was nogo and the flanker a go digit than when both central and flanking digits were go digits. The size of this difference was not affected by go prevalence over a range from 50% to 90%.

The finding that the probability of nogo error is affected by congruency is notable. All theories of SART performance agree that responses to nogo stimuli occur because information regarding stimulus classification as go vs. nogo has not been extracted or not used to determine action. If that is true how is an accuracy FCE possible on nogo trials? The implication from a nogo accuracy FCE is that stimulus information is available, at least on some occasions, when a response has been made to a nogo display, although the speed of response was not affected by display congruency. One way to account for the effect of congruency on the rate of nogo errors is to suppose that stimulus information accrues over time automatically from the moment of abrupt change to a level where digits are classified as go or nogo regardless of allocation of attention (Kouider & Dehaene, 2007; Lehle & Hübner, 2008). At the same time an extended set of motor processes that control the initiation and production of the go response unfolds. If stimulus extraction occurs quickly relative to response production then classification of the stimulus as nogo may occur soon enough to halt the response production processes before an overt response is produced (Aron, 2011). Classification will occur soon enough to prevent overt response more often for congruent than incongruent displays because conflicting classifications are extracted from incongruent displays and these take additional time to resolve (Eriksen & Eriksen, 1974; Sanders & Lamers, 2002). However, RTs of responses to nogo displays will not be affected by congruency. When classification of the display as nogo occurs too late to prevent an overt response, a response is made and its latency is determined by the speed of execution of response processes, which presumably are similar regardless of the classification of the display.

The idea that nogo errors occur when response production processes outpace concurrently running stimulus extraction processes suggests that manipulations which speed stimulus classification relative to response production should reduce the probability of nogo error. This prediction was explored in Experiment 6 (chapter 8) by varying the locations of go and nogo stimuli in an adaption of the usual high go SART procedures. In the traditional SART all stimuli are presented centrally and classification of stimuli as go or nogo requires discrimination between Arabic numerals, or at least the distinction between “3” and the remaining digits. However the need to discriminate digits is by-passed when all go digits appear centrally and nogo digits are displaced peripherally to the left or right. The probability of nogo error fell from near .50 to near .15 when go vs nogo digit classification could be determined from location without the necessity to consider digit identity. At the same time go RTs fell from around 280 ms to less than 240 ms and the usual difference in RT between go and nogo digits disappeared.

Typically, with the SART speedier response is associated with higher probability of nogo error. The finding of faster responses and reduced probability of error shows that errors in the SART are not inevitably a consequence of trading speed for accuracy. In this case classification of go stimuli was fast because go stimuli occurred at an attended location and nogo stimuli occurred outside of it. Errors were much less common because relative to response execution, stimulus classification was fast. But typically when subjects increase response speed stimulus extraction processes become relatively slower so that response processes have proceeded beyond the stage that stimulus classification can stop overt action. Consequently, the probability of nogo error increases with speed of response.

Experiment 6 also included a reverse arrangement in which all nogo stimuli were centrally located and go digits appeared equally often to the left or right (PC condition). This time probability of nogo errors fell but only to about .35 while go RTs were virtually the same as those in the CC condition and slower than nogo responses. In some regards the CP and PC conditions are similar. Both appear to involve the same response requirements and go and nogo stimuli are discriminable by location alone in both conditions. But they differ in terms of the way visual attention might be allocated across the screen. When all go stimuli appear in the centre of the screen and infrequent nogo stimuli occur to the left or right, discrimination of go from nogo is likely to be fast – if screen change occurs in the centre respond otherwise do not respond. But when go stimuli are displayed equally often at different locations on either side of the screen and rarer nogo digits appear only in the centre either the attentional field will encompass all areas, or attention might be focused on one location at the expense of others requiring redirection of attention as part of the stimulus classification process. In both cases classification of stimuli as go vs. nogo is likely to be retarded relative central go peripheral nogo arrangement. If response processes are the same, then the relative speed of classification is slower when go stimuli are split between two peripheral locations and hence go RTs will be longer and nogo errors more common when go stimuli are split between two locations.

Experiment 6 has relevance for the claim that lapses in attention occur in the SART because its repetitive and unvarying nature provide little exogenous support for the maintenance of attention to the task. Robertson et al. interpreted this to mean the repetitive response requirements of a high go task. The term perceptual decoupling implies that it is lack of variation in stimulus properties which leads to the disengagement of attention from the task. Spatial variation in the context of identical response requirements increases stimulus variation, and therefore increases exogenous support for the maintenance of attention on the task. Stimulus variety can be quantified using information metrics of uncertainty. Uncertainty or variety is greater in Experiment 4 when go stimuli were split between two peripheral locations than when all go stimuli were centrally located. Contrary to predictions based on exogenous support nogo errors (instances of attention disengagement) were higher, not lower, when variety was greater.

Over all the results from the current Experiments provide little support for the idea that nogo errors occur because lack of task variety encourages mind-wandering and a disconnection between attention and perceptual processes of information extraction relating to stimulus classification as go vs. nogo. The factors that most strongly determine the probability of overt response to a nogo stimulus appear to be: the proportion of go trials and manipulations that affect the relative speed of information extraction and response production processes. Proportion of go trials affects probability of nogo error because it both alters the relative benefit of speed over the cost of error and determines the level of preparedness and anticipation that overt response is appropriate. The relative speed of stimulus classification involves such manipulations as delaying response production or lengthening the execution process and expediting stimulus classification (e.g. location, colour, and other salient differences between go and nogo stimuli). Future research could perhaps deal with the predictable occurrence of stimuli in the SART by varying the ISI or even alter the nature of the response by having subjects press a sequence of buttons for go stimuli. This would allow insight into the race for perceptual processes to catch up to motor processes.

To conclude, we could say that in a sense perceptual decoupling may be correct in its explanation of nogo errors in high go situations, errors do occur when stimulus information is not extracted, but the reason is not disengagement of attention from perception, extraction processes continue without attention. The reason is the inability to control a highly prepared response process triggered by abrupt change which does not allow time for perception to proceed and allow stimulus classification to control action. Both motor and perception decoupling are in a sense correct, it is just that inability to control an automated motor act is prior, it is the reason the product of perceptual processes arrives too late to stop the inappropriate response before completion.

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